IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

POLAROID CORPORATION, Plaintiff and Counterclaim-Defendant, v. HEWLETT-PACKARD COMPANY, Defendant and Counterclaim-Plaintiff.	C.A. No. 06-738 (SLR)

JOINT APPENDIX ON CLAIM CONSTRUCTION

MORRIS, NICHOLS, ARSHT &
TUNNELL LLP
Jack B. Blumenfeld (#1014)
Julie Heaney (#3052)
1201 N. Market Street
Wilmington, Delaware 19801
(302) 658-9200

OF COUNSEL:

KIRKLAND & ELLIS LLP
Russell E. Levine, P.C.
C. Graham Gerst
Michelle W. Skinner
David W. Higer
Maria A. Meginnes
Courtney Holohan
Michelle W. Jordan
200 East Randolph Drive
Chicago, IL 60601
(312) 861-2000

Attorneys for Plaintiff
Polaroid Corporation

FISH & RICHARDSON P.C.
William J. Marsden, Jr. (#2247)
919 N. Market Street, Suite 1100
Wilmington, DE 19801
(302) 652-5070

John E. Giust
Matthew E. Bernstein
12390 El Camino Real
San Diego, CA 92130
Telephone: (858) 678-5070

Bradley D. Coburn
111 Congress Avenue, Suite 810
Austin, TX 78701
Telephone: (512) 472-5070

CHOATE, HALL & STEWART
Daniel C. Winston
Two International Place
Boston, MA 02110
Telephone: (617) 248-5000

Attorneys for Defendant and Counterclaim-
Plaintiff Hewlett-Packard Company

Dated: January 11, 2008

[redacted]

4829381

4829381

IAL IBER es 987)	PATENT DATE	PATENT NUMBER
7182987	MAY 09 1989	

SERIAL NUMBER	FILING DATE	CLASS	SUBCLASS	GROUP ART UNIT	EXAMINER
07/182,987	04/18/88	358		262	

WOO-JIN SONG, WALTHAM, MA; DONALD S. LEVINSTONE, LEXINGTON, MA.

CONTINUING DATA********************

VERIFIED

10-3-88

FOREIGN/PCT APPLICATIONS**********

VERIFIED

10-2-88

FOREIGN FILING LICENSE GRANTED 05/31/88

eign priority claimed / USC 119 conditions met / ified and Acknowledged	AS FILED	STATE OR COUNTRY	SHEETS DRWGS.	TOTAL CLAIMS	INDEP. CLAIMS	FILING FEE RECEIVED	ATTORNEY'S DOCKET NO.
☐yes ☒no / ☐yes ☒no / Examiner's Initials		MA	2	15	4	$ 374.00	7464

POLAROID CORPORATION
PATENT DEPARTMENT
549 TECHNOLOGY SQ.
CAMBRIDGE, MA 02139

SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION

U.S. DEPT. of COMM.-Pat. & TM Office — PTO-436L (rev. 10-78)

LN

RTS OF APPLICATION
ED SEPARATELY

ICE OF ALLOWANCE MAILED	PREPARED FOR ISSUE 1-5-89		CLAIMS ALLOWED	
			Total Claims	Print Claim
1-4-89	E. Anne Faris / Assistant Examiner	Nancy Noland / Docket Clerk	13	1

ISSUE FEE		Primary Examiner	DRAWING		
unt Due	Date Paid	James J. Groody / Supervisory Patent Examiner / Art Unit 262	Sheets Drwg.	Figs. Drwg.	Print Fig.
0.00	3-3-89		2	4	4

ISSUE CLASSIFICATION		ISSUE BATCH NUMBER
Class	Subclass	P-19
358	168	

Label Area

WARNING: The information disclosed herein may be restricted. Unauthorized disclosure may be prohibited by the United States Code Title 35, Sections 122, 181 and 368. Possession outside the U.S. Patent & Trademark Office is restricted to authorized employees and contractors only.

APPROVED FOR LICENSE ☐

INITIALS ______

CONTENTS

Entered or Counted			Received or Mailed
	1.	Application papers.	
	2.	Rej (3mos)	10-14-88
	3.	Examiner Interview	10-18-88
	4.	Letter (3mos)	10-20-88
10-31	5.	[illegible]	[illegible] 1988
12-20-88	6.	[illegible]	Dec. 19 1988
	7.	Notice of Allowability	Jan 4, 1989
	8.		
	9.		
	10.		
	11.		
	12.		
	13.		
	14.		
	15.		
	16.		
	17.		
	18.		
	19.		
	20.		
	21.		
	22.		
	23.		
	24.		
	25.		
	26.		
	27.		
	28.		
	29.		
	30.		
	31.		
	32.		

Staple Issue Slip Here

INDEX OF CLAIMS

Claim		Date								
Final	Original	10/3/88	12/27/88							
1	1	✓	=							
2	2	✓	=							
	~~3~~	✓								
3	4	✓	=							
4	5	✓	=							
5	6	✓	=							
6	7	✓	=							
7	8	✓	=							
8	9	✓	=							
	~~10~~	✓								
9	11	✓	=							
10	12	✓	=							
11	13	✓	=							
12	14	✓	=							
13	15	✓	=							
	16									
	17									
	18									
	19									
	20									
	21									
	22									
	23									
	24									
	25									
	26									
	27									
	28									
	29									
	30									
	31									
	32									
	33									
	34									
	35									
	36									
	37									
	38									
	39									
	40									
	41									
	42									
	43									
	44									
	45									
	46									
	47									
	48									
	49									
	50									

Claim		Date								
Final	Original									
	51									
	52									
	53									
	54									
	55									
	56									
	57									
	58									
	59									
	60									
	61									
	62									
	63									
	64									
	65									
	66									
	67									
	68									
	69									
	70									
	71									
	72									
	73									
	74									
	75									
	76									
	77									
	78									
	79									
	80									
	81									
	82									
	83									
	84									
	85									
	86									
	87									
	88									
	89									
	90									
	91									
	92									
	93									
	94									
	95									
	96									
	97									
	98									
	99									
	100									

SYMBOLS

✓ .... Rejected
= .... Allowed
- (Through numeral) Canceled
+ .... Restricted
N .... Non-elected
I .... Interference
A .... Appeal
O .... Objected

[redacted]

SEARCHED

Class	Sub.	Date	Exmr.
358	166		
	167		
	36		
	37		
	168		
	169		
	32		
	164	10-2-88	GZ
To date		12/27/88	GZ

SEARCH NOTES

	Date	Exmr.
T. Chin	10-2-88	GZ

INTERFERENCE SEARCHED

Class	Sub.	Date	Exmr.
358	165		
	166		
	32		
	164	12/27/88	GZ

United States Patent [19]
Song et al.

[11] **Patent Number: 4,829,381**
[45] **Date of Patent: May 9, 1989**

[54] **SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION**

[75] Inventors: **Woo-Jin Song**, Waltham; **Donald S. Levinstone**, Lexington, both of Mass.

[73] Assignee: **Polaroid Corporation**, Cambridge, Mass.

[21] Appl. No.: **182,987**

[22] Filed: **Apr. 18, 1988**

[51] Int. Cl.[4] H04N 5/235; H04N 5/208
[52] U.S. Cl. 358/168; 358/166; 358/32; 358/164
[58] Field of Search 358/166, 167, 36, 37, 358/168, 169, 32, 164

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,215,294	7/1980	Taggart	358/168 X
4,334,244	6/1982	Chan et al.	358/166
4,489,349	12/1984	Okada	358/168
4,523,230	6/1985	Carlson et al.	358/167
4,549,212	10/1985	Bayer	358/167
4,568,978	2/1986	Cosh	358/32 X
4,663,667	5/1987	Shenk	358/169
4,751,566	6/1988	Pilot	358/32

FOREIGN PATENT DOCUMENTS

2312150	12/1976	France	358/164
1605009	12/1981	United Kingdom	358/168

Primary Examiner—James J. Groody
Assistant Examiner—E. Anne Faris
Attorney, Agent, or Firm—Edward S. Roman

[57] **ABSTRACT**

A system and method are provided for continuously enhancing electronic image data received in a continuous stream of electronic information signals wherein the electronic information signal corresponding to each pixel of the image recorded is selectively transformed as a function of the average value of electronic information signals for a select plurality of pixel values in the immediate area of the pixel value being transformed. The electronic information signal transformations are provided on a pixel-by-pixel basis to increase contrast in localized areas that may be either exceptionally light or dark as a result of varying scene lighting conditions.

13 Claims, 2 Drawing Sheets

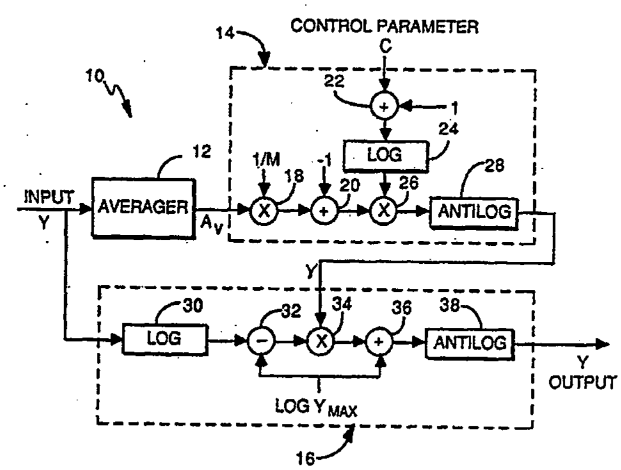


FIG 1

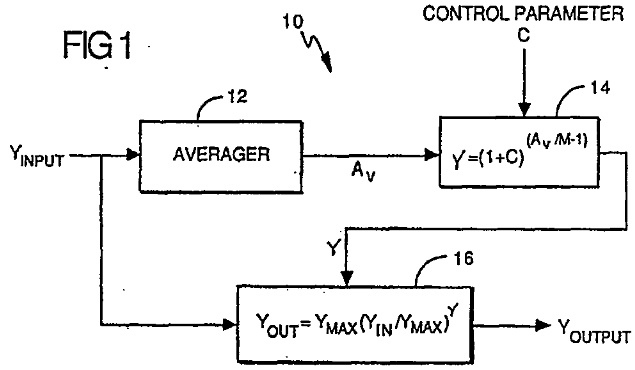
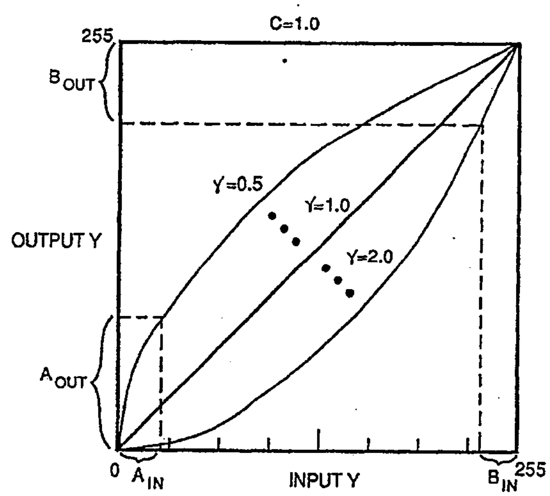

10
CONTROL PARAMETER
C
14
12
Y_{INPUT}
AVERAGER
A_V
$\gamma=(1+C)^{(A_V/M-1)}$
γ
16
$Y_{OUT}=Y_{MAX}(Y_{IN}/Y_{MAX})^{\gamma}$
Y_{OUTPUT}

FIG 2


C=1.0
255
B_{OUT}
OUTPUT Y
γ=0.5
γ=1.0
γ=2.0
A_{OUT}
0
A_{IN}
INPUT Y
B_{IN}
255

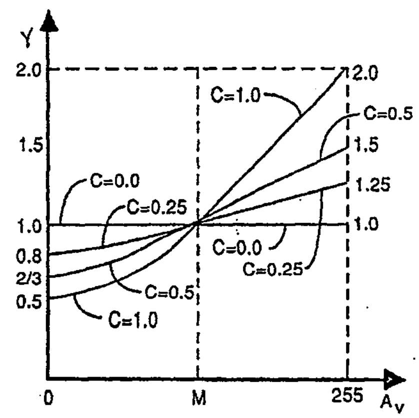

Y
2.0
1.5
1.0
0.8
2/3
0.5
0
M
255
A_V
C=1.0
C=0.5
C=0.25
C=0.0
2.0
1.5
1.25
1.0

FIG 3

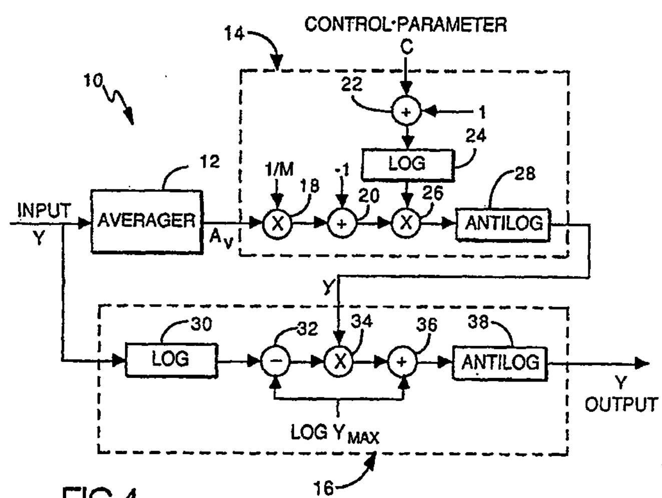

CONTROL PARAMETER
C
14
10
22
1
24
LOG
12
1/M
-1
18
20
26
28
INPUT
Y
AVERAGER
A_V
ANTILOG
Y
30
32
34
36
38
LOG
ANTILOG
Y
OUTPUT
LOG Y_{MAX}
16

FIG 4

SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to a system and method for electronic image enhancement by dynamic pixel transformation and, more particularly, to a system and method for enhancing electronic image information by dynamically transforming electronic information signals on a pixel-to-pixel basis.

2. Description of the Prior Art

Electronic still image cameras are becoming well known in the art. Such cameras utilize photoresponsive arrays to sense scene light and convert the sensed scene light into electronic information signals. Electronic information signals are thereafter stored on a suitable media which may include magnetic, optical or solid state storage for subsequent retrieval and viewing. It may be desirable at some point to transform the stored image defining electronic information signals to a hard copy of the scene originally recorded. Photographic media have been suggested and used for such purposes. Difficulties arise, however, as a result of differences between the wide dynamic range of the scene originally sensed and recorded and the substantially smaller dynamic range to which a photographic print may be exposed. The wide dynamic range of luminance intensities within the scene originally recorded may thus be compressed or clipped to the substantially smaller dynamic range of the photographic print, losing detail within certain portions of the dynamic range that were otherwise visible in the original scene. Thus, it may be desirable to transform the original image defining electronic information signals in a nonlinear manner to selectively increase and/or decrease the contrast and brightness in certain portions of the scene such as those that might be brightly lit by sunlight or underlit as a result of shadows. However, no single transform function can be uniformly applied to all the image defining electronic information signals of the scene and achieve satisfying results because the lighting conditions vary across the scene.

Therefore, it is an object of this invention to provide a system and method of electronically enhancing images by dynamically increasing or decreasing contrast and brightness in selected portions of the scene that may be overlit or underlit.

It is a further object of this invention to provide a system and method of enhancing image defining electronic information signals in a dynamic manner on a pixel-by-pixel basis such that the value of each pixel is selectively transformed as a function of the average value of a plurality of pixels closely spaced about that pixel.

Other objects of the invention will be in part obvious and will in part appear hereinafter. The invention accordingly comprises a mechanism and system possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure.

SUMMARY OF THE INVENTION

A system is provided for enhancing electronic image data received in a continuous stream of electronic information signals wherein each signal corresponds to one of a plurality of succeeding pixels. The pixels collectively define the image to be recorded. Means are provided for averaging the electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each of the plurality of the pixels so averaged. Means operate to thereafter select one of the plurality of different transfer functions of electronic information signals for each of the succeeding pixels. Each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing that one pixel. The electronic information signal corresponding to each pixel is subsequently transformed by the transfer function selected for that pixel. The system responds to an average electronic information signal indicative of low scene light intensity levels by transforming electronic information signals to provide a higher contrast and/or brightness to those electronic information signals corresponding to pixels having the lowest scene light intensity levels. The system also responds to an average electronic information signal indicative of high scene light intensity levels by transforming electronic information signals to provide a higher contrast and/or lower brightness to those electronic information signals corresponding to pixels having the highest scene light intensity levels.

DESCRIPTION OF THE DRAWINGS

The novel features that are considered characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with other objects and advantages thereof will be best understood from the following description of the illustrated embodiment when read in connection with the accompanying drawings wherein:

FIG. 1 is a block diagram showing the system for enhancing electronic image data in the manner of this invention;

FIG. 2 is a graphical representation showing the output electronic information signals versus the input electronic information signals;

FIG. 3 is a graphical representation showing the variation of gamma γ with different selected control parameters; and

FIG. 4 is a block diagram showing in substantially more detail a system for enhancing electronic image data of this invention in the manner of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In electronic image processing it is desirable to adjust the image contrast automatically to produce more detail in both the bright and dark areas of a scene that is recorded. The image enhancing system and method of this invention operates to both lighten the dark regions of a scene and darken the light regions of a scene by enhancing contrast to improve the detail visibility that would otherwise be lost when the electronic image signals are converted to a hard copy reproduction. Toward that end, the system and method of this invention operates to continuously enhance electronic image data received in a continuous stream of electronic information signals, each signal of which corresponds to one of the plurality of succeeding pixels which collectively define the recorded image.

Referring now to FIG. 1, there is shown a block diagram for the system of this invention in which a continuous stream of electronic information signals each corresponding to one of a plurality of succeeding pixels from the recorded image are received at terminal Y_{input}. The electronic information signals input at terminal Y_{input} may be derived in a well-known manner by a two-dimensional photosensitive array or sensor (not shown) which may comprise a high resolution charge coupled device (CCD) or charge injection device (CID). The sensor receives image scene light in any well-known manner by way of an objective lens and shutter (also not shown). The image sensing array comprises a plurality of image sensing elements or pixels preferably arranged in a two-dimensional area array wherein each image sensing pixel converts the incident image defining scene light rays into a corresponding analog electronic information signal value. Preferably, the image sensing pixels are arranged in columns and rows as is well known in the art. As will be readily understood, image sensing arrays, particularly for sensing still images, preferably comprise a large number of image sensing elements or pixels in the order of 500,000 or greater.

The two-dimensional photosensitive arrays may also be overlayed with any one of a variety of different well-known filter patterns so that each pixel provides an electronic information signal value corresponding to a particular color. For instance, the columns of the two-dimensional photosensitive array may be overlayed with any one of a red, green or blue filter stripe arranged in a repeating fashion across the face thereof. The electronic information signal value for each pixel in this arrangement thus corresponds to a particular color.

The electronic information signal values retrieved from the photosensitive array in this manner are preferably converted to luminance (Y) and chrominance, e.g., (R-Y and B-Y) signal values. For the case where the two-dimensional photosensitive array is overlayed with red, green and blue filters, the luminance electronic information signals are preferably determined by the following relationship: $Y=0.30R+0.59G+0.11B$ as is well known in the television art. The analog luminance electronic information signal values for each pixel element of the photosensitive array for the example herein described are digitized to an 8-bit binary number so as to have a dynamic integer range of from 0 - 255 within which range are 256 intensity levels and a maximum luminance value of $Y_{MAX}=255$. The electronic image detection and processing herein described so far will be recognized as being conventional and well known in the art.

The image defining electronic information signals derived in the above-described manner and preferably comprising digitized luminance signals are thereafter subjected to a gain control function which may be automatic as is well known in the art before being directed to input terminal Y_{input} of the block diagram of FIG. 1. The image defining luminance electronic information signals are thereafter averaged for selected pluralities of pixels by an averager 12. The averager 12 may comprise a low pass filter as is well known in the art which operates to provide an average value electronic information signal Av corresponding to the average luminance values for a selected window or plurality of pixels that continuously changes in correspondence with each succeeding pixel value to be enhanced. Alternatively, the averager may comprise a block average in which a selected group or block of pixel values is averaged to provide one average value electronic information signal Av in correspondence with each pixel value of that group to be enhanced. Succeeding groups of pixel values are thereafter averaged. In the preferred mode, the selected groups of pixels are preferably selected in two dimensions from the photosensitive array.

Both low pass filtering and block averaging require a buffer memory to hold the selected groupings of pixel values for averaging as is well known in the art. The low pass filter method results in a continuing change in the average value of the electronic information signal Av for each succeeding pixel thereby providing a more accurate determination of average values for selecting the appropriate transfer function in the manner of this invention to be described. However, as will be well understood, the low pass filtering technique requires a substantially increased computational capacity in comparison to block averaging; and, therefore, block averaging, although not as highly selective as low pass filtering, may be preferred in image enhancing applications where reduced computational capacity is desired. Low pass filtering and block averaging are both well-known techniques in the electronic arts and therefore need not be described in any further detail herein.

The average value for the image defining luminance electronic information signal (Av) is thereafter provided to a gamma determining circuit 14 which determines gamma as a function of the average value input thereto in accordance with the following relationship:

$$\gamma=(1+C)(Av/M-1)$$

In the above relationship M for this example is selected to be the center value of the dynamic range of the electronic information signals. As was previously stated, the electronic signal values for this example comprise 8-bit binary numbers having a dynamic range of 256. Thus, for this example, $M=128$. However, it will be readily understood that M may be selected to be any value within the dynamic range of the electronic information signals depending upon where the least image enhancement is desired. Thus, for the case where M is selected to be at the center of the dynamic range, image enhancement will have the greatest effect near the ends of the dynamic range and the least effect toward the center of the dynamic range. Selecting the value of M to be closer to the high end of the dynamic range will decrease the effective image enhancement provided at that end by the system and method of this invention.

C is a control parameter selected in the manner of this invention to vary the amount of image enhancement that may be provided by the system and method of this invention in a manner to be more fully described in the following discussion.

The value of gamma is thereafter directed to a transfer function imposing circuit 16 which operates to impose the following transfer function on the image defining luminance electronic information signals (Y) received at input terminal Y_{input} and corresponding to each one of the succeeding pixels which collectively define the recorded image.

$$Y_{out}=Y_{MAX}(Y_{in}/Y_{MAX})^{\gamma}$$

Y_{MAX} equals the highest value of the dynamic range for the electronic information signals or 255 for the example herein described. Y_{out} equals the image defining

luminance electronic information signal transformed in the manner of this invention to provide an enhanced image. As is now readily apparent, it is selected for the image defining luminance electronic information signal for each pixel as a function of a local average of image defining luminance electronic information signals for a select group or plurality of pixels closely spaced about the pixel value being enhanced or transformed. Thus, gamma γ changes continuously in correspondence with the average values from the continuous stream of succeeding image defining luminance electronic information signals so that each image defining luminance electronic information signal is enhanced or transformed by a selected one of a plurality of different transfer functions.

Referring now to FIG. 2, there is shown a graphical representation of the various transfer functions that are imposed by the transfer function circuit 16 as a function of the variation in gamma γ. For the example as shown in FIG. 2, the control parameter C is selected to equal 1 and thus it can be seen that gamma γ has a variation of from 0.5 to 2. For instance, in the situation where the average value of the image defining luminance electronic signals is high and approaches the maximum value of the dynamic range which in this example equals 255 and is indicative of a portion of the image that is extremely bright, it can be seen that gamma γ equals 1+C or as in the case where C=1, gamma $\gamma=2$ as shown in the diagram of FIG. 2. The slope of the transfer function as is readily apparent for the situation where gamma $\gamma=2$ becomes quite steep at the high end of the dynamic range (B_{in}, B_{out}) thereby providing a higher contrast to those image defining luminance electronic information signals corresponding to pixels having the highest scene light intensity levels. The slope of the transfer function for $\gamma=2$ decreases significantly at the low end of the dynamic range (A_{in}, A_{out}) thereby providing a lower contrast to those image defining luminance electronic information signals corresponding to pixels having the lowest scene light intensity levels. Since M is selected to be at the center of the dynamic range, it can be seen that the slope of the transfer function at the center of the dynamic range most closely approximates that of a straight line thereby providing the least effect on the output signal for pixels having intensity levels near the center of the dynamic range.

Conversely, in the situation where the average values of the image defining luminance electronic information signals are low approaching 0 indicative of localized areas of low scene light intensity levels, then gamma $\gamma=1$ divided by 1+C which equals 0.5 in the case where C=1. The transfer function imposed by the transfer function circuit 16 in the case where gamma γ equals 0.5 is shown graphically in FIG. 2 as comprising a substantially steep slope in the areas (A_{in}, A_{out}) where the image defining luminance electronic information signal values are low. Thus, the transfer function in this case where gamma γ equals 0.5 operates to transform the image defining luminance electronic information signals to provide a high contrast to those electronic information signals corresponding to pixels having the lowest scene light intensity levels. The slope of the transfer function for $\gamma=0.5$ decreases significantly at the high end of the dynamic range (B_{in}, B_{out}) thereby providing a lower contrast to those image defining luminance electronic information signals corresponding to pixels having the highest scene light intensity levels. Again, since M is selected to be at the center of the dynamic range, it can be seen that the slope of the transfer function at the center of the dynamic range most closely approximates that of a straight line thereby providing the least effect on the output signal for pixels having intensity levels near the center of the dynamic range. It can be seen that the transfer function imposed by the transfer function circuit 16 can have any intermediate number of transfer functions shown between the extreme end transfer functions where gamma equals 0.5 or 2.0 and that all of the transfer functions are operative for the full extent of the input dynamic range so as not to clip the input signal values.

In the situation where the average value for the image defining luminance electronic information signal values corresponds to the intermediate value of the dynamic range, gamma $\gamma=1$ and the transfer function becomes a straight line to provide a one-to-one relationship between the input and output electronic information signals with no localized increase in contrast as provided by the other transfer functions where gamma γ is either greater or less than 1. Thus, in this manner in a situation where a scene may have localized dark or bright areas, there may be provided a localized increase in the contrast to those areas to make visible details that otherwise would be lost. The transfer functions vary in correspondence with the variation in the local average scene light intensity levels so as to apply the increased contrast selectively to those light or dark portions of the scene where details are otherwise obscured.

Referring now to FIG. 3, there is shown a graphical representation of the variation in gamma γ as a function of the variation of the control parameter C. Thus, it can be seen that for a control parameter C value of 1 gamma γ varies from 0.5 to 2. If the control parameter C is selected to be 0, gamma γ remains constant at 1. Although for a typical imaging application which requires dynamic range compression, it may be satisfactory to select the control parameter C to equal 1 thereby achieving an extreme variation in gamma from 2 to 0.5, it may be desirable to increase the amount of localized contrast thereby selecting values of the control parameter C greater than 1.

Referring now to FIG. 4 where like numerals reference previously discussed components, there is shown a circuit diagram for implementing a transfer function as described in connection with FIG. 1. The aforementioned transfer function may be converted to the following relationship by taking the logarithm on both sides of the aforementioned equation.

$$\log Y_{out}=\log Y_{MAX}+\gamma(\log Y_{in}-\log Y_{MAX})$$

Similarly, the relationship for determining gamma can also be rewritten as follows:

$$\log \gamma=(Av/M-1)[\log(1+C)]$$

These relationships can be implemented as shown by the circuit of FIG. 4. The average value of the image defining luminance electronic information signal is first directed to a multiplier circuit 18 where the signal is multiplied by 1/M where M equals one-half the dynamic range of the electronic information signals as previously discussed. The output from the multiplier circuit 18, in turn, is directed to a combining circuit 20 which operates to add a negative 1 to the output from the multiplier circuit 18. The control parameter C is directed to a combiner circuit 22 which operates to add

a positive 1 thereto. The output from the combiner circuit 22, in turn, is directed to a log circuit 24 which provides the logarithmic value for the C+1 input thereto. The output from the logarithmic circuit 24, in turn, is multiplied by the output from the combining circuit 20 by a multiplier circuit 26. The output from the multiplier circuit 26, in turn, is directed to an antilogarithmic determining circuit 28 which operates utilizing a lookup table to provide the antilogarithm creating the value of gamma γ.

The image defining luminance electronic information signal for each pixel, in turn, is directed to a logarithm determining circuit 30 in the transfer function circuit 16. The output from the logarithm determining circuit 30, in turn, is directed to a combiner circuit 32 which operates to subtract therefrom the logarithm for the maximum dynamic range of the electronic information signals. The output from the combiner 32, in turn, is multiplied by multiplier circuit 34 by the value of gamma γ received from the antilogarithm determining circuit 28. The output from the multiplier 34, in turn, is directed to a combiner circuit 36 for addition to the logarithm of the maximum dynamic range of the electronic information signals. The output from the combiner circuit 36, in turn, is directed to an antilogarithm determining circuit 38 to provide the transformed image defining luminance electronic information signals Y_{out} as shown. Thus, in this manner, gamma γ is determined continuously in accordance with the relationship as shown by the block diagram of FIG. 1 in a simple and convenient manner utilizing multiplication circuits, combining circuits, logarithm determining circuits, and antilogarithm determining circuits as shown in FIG. 4. In like manner, the transfer function continuously varied in accordance with the selection of gamma may also be imposed continuously in a simple and convenient manner by circuitry comprising a logarithm determining circuit, combining circuits, multiplication circuit, and an antilogarithm determining circuit. Thus, in this manner localized dynamic contrast enhancement can be provided as a function of dynamic gamma transformation on a pixel-by-pixel basis.

Thus, the system and method of this invention provides for enhancing electronic image data in a manner involving a relatively small number of computations that can be easily calculated in a continuous manner. All of the transfer functions that can be invoked are of a continuous nature without any sharp discontinuities that could otherwise result in undesirable artifacts appearing in the final image. In addition, as previously mentioned, none of the transfer functions operate to clip any portion of the incoming electronic information signal, thus resulting in the entire dynamic range of the incoming signal being transformed.

Other embodiments of the invention including additions, subtractions, deletions and other modifications of the preferred disclosed embodiments of the invention will be obvious to those skilled in the art and are within the scope of the following claims.

What is claimed is:

1. A system for continuously enhancing electronic image data received in a continuous stream of electronic information signals, each signal having a value within a determinate dynamic range of values and corresponding to one of a plurality of succeeding pixels which collectively define an image, said system comprising:

means for averaging electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels so averaged; and

means for selecting one of a plurality of different transfer functions for the electronic information signal for each of the succeeding pixels in a manner whereby each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing said one pixel and for subsequently transforming the electronic information signal corresponding to each pixel by the transfer function selected for that pixel wherein said selecting and transforming means further operates to select said transfer function as a function of the ratio of the value of the average electronic information signal to the dynamic range of the electronic information signals such that the ratio increases in correspondence with the increase in the value of the average electronic information signal.

2. The system of claim 1 wherein said selecting and transforming means is responsive to an average electronic information signal indicative of low scene light intensity levels for transforming the electronic information signals to provide a higher contrast to those electronic information signals corresponding to pixels having the lowest scene light intensity levels and is further responsive to an average electronic information signal indicative of high scene light intensity levels for transforming the electronic information signals to provide a higher contrast to those electronic information signals corresponding to pixels having the highest scene light intensity levels.

3. The system of claim 2 wherein said selecting and transforming means further operates to select said transfer function as a function of a determined constant whose value corresponds to the amount of contrast provided in those areas of higher contrast provided by said select transfer function.

4. The system of claim 3 wherein said selecting and transforming means further operates to determine the select transfer function as a function of the determination of gamma (γ), said selecting and transforming means including means for determining gamma (γ) in accordance with the relationship

$$\gamma=(1+C)(Av/M-1)$$

where C equals said determined constant, Av equals the average electronic information signal value and M equals a select proportionate value of the dynamic range of the electronic information signals.

5. The system of claim 4 wherein said transforming means transforms the electronic information signal of each pixel in accordance with the relationship

$$Y_{out}=Y_{MAX}(Y_{in}/Y_{MAX})^{\gamma}$$

where Y_{in} equals the value of the electronic information signal of the pixel to be enhanced, Y_{out} equals the enhanced value of the input electronic information signal and Y_{MAX} equals the highest value of the dynamic range for the electronic information signals.

6. A system for enhancing electronic image data received in a continuous stream of electronic information signals each signal having a value within a determinate dynamic range of values and corresponding to one of a

plurality of succeeding pixels which collectively define an image, said system comprising:

means for averaging electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels so averaged;

means for dividing each of the average electronic information signals corresponding to each pixel by a value M corresponding to a select proportionate value of the dynamic range of said electronic information signals;

first means for subtracting 1 from each of the electronic information signals output by said dividing means;

first means for adding a select control parameter and 1;

first means for determining the logarithm of the output from said first adding means;

first means for multiplying the output from said first logarithm determining means by the output from said first subtracting means;

first means for determining the antilogarithm of the output from said first multiplying means;

second means for determining the logarithm for each of the continuous streams of electronic information signals;

second means for subtracting the logarithm for a value corresponding to the maximum value of the electronic information signals from the output of said second logarithm determining means;

second means for multiplying the output of said first antilogarithm determining means by the output from said second subtracting means;

second means for adding the logarithm of the value corresponding to the maximum value of the electronic information signals to the output from said second multiplying means; and

second means for determining the antilogarithm of the output from said second adding means to provide an enhanced output signal value.

7. A method for continuously enhancing electronic image data received in a continuous stream of electronic information signals each signal having a value within a determinate dynamic range of values and corresponding to one of a plurality of succeeding pixels which collectively define an image, said method comprising the steps of:

averaging the electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels;

selecting one of a plurality of different transfer functions for the electronic information signal for each of the plurality of succeeding pixels in a manner whereby each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing said one pixel; and

transforming the electronic information signal corresponding to each pixel by the transfer function selected for that pixel wherein said transfer function is selected further as a function of the ratio of the value of the average electronic information signal to a select proportionate value of the dynamic range of the electronic information signals such that the ratio increases in correspondence with the increase in the value of the average electronic information signal.

8. The method claim 7 wherein the transfer function is selected: in response to an average electronic information signal indicative of low scene light intensity levels to provide a higher contrast to those electronic information signals corresponding to pixels having the lowest scene light intensity levels and in response to an average electronic information signal indicative of high scene light intensity levels to provide a higher contrast to those electronic information signals corresponding to pixels having the highest scene light intensity levels.

9. The method of claim 8 wherein said transfer function is selected further as a function of a determined constant wherein increasing the value of said constant operates to increase the contrast in those areas of higher contrast provided by said select transfer function.

10. The method of claim 9 wherein said transfer function is selected as a function of the determination of gamma (γ) and gamma (γ) is determined for each pixel in accordance with the relationship

$$\gamma=(1+C)(Av/M-1)$$

where C equals said determined constant, Av equals the average electronic information signal value and M equals said value for one-half the dynamic range of the electronic information signals.

11. The method of claim 10 wherein said select transfer function for the electronic information signal of each pixel comprises the relationship

$$Y_{out}=Y_{MAX}(Y_{in}/Y_{MAX})^{\gamma}$$

where Y_{in} equals the value of the electronic information signal of the pixel to be enhanced, Y_{out} equals the enhanced value of the input electronic information signal and Y_{MAX} equals the highest value of the dynamic range for the electronic information signals.

12. A method for enhancing electronic image data received in a continuous stream of electronic information signals each signal corresponding to one of a plurality of succeeding pixels which collectively define an image, said method comprising the steps of:

averaging the electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels;

dividing each of the average electronic information signals corresponding to each pixel by a value M corresponding to a select proportionate value of the dynamic range of said electronic information signals;

subtracting 1 from each of the electronic information signals previously divided by the value M to provide a first intermediate signal value;

selecting a control parameter C as a function of the amount of image enhancement to be applied;

adding 1 to the control parameter C;

determining the logarithm of the control parameter C plus 1;

multiplying the logarithm of the control parameter C plus 1 by said first intermediate signal value to provide a second intermediate signal value;

determining the antilogarithm of the second intermediate signal value;

determining the logarithm for each of the continuous streams of electronic information signals;

subtracting from the previously determined logarithm for each of the continuous streams of electronic information signals the logarithm for a value corresponding to the maximum value of the electronic information signals to provide a third intermediate signal value;

multiplying the antilogarithm of the second intermediate signal value by the third intermediate signal value to provide a fourth intermediate signal value;

adding the logarithm of the value corresponding to the maximum value of the electronic information signals to the fourth intermediate signal value to provide a fifth intermediate signal value; and

determining the antilogarithm of the fifth intermediate signal value to provide an enhanced output signal value.

13. The method of claim 12 wherein said image enhancement operates to increase image contrast locally in areas of pixels having low contrast and said control parameter C is determined as a function of the amount of local contrast variation to be provided.

* * * * *

PATENT APPLICATION SERIAL NO. 182987

Granting 6/28

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

PTO-1556
(5/87)

Patent Departm
Polaroid Corporation
Cambridge, Massachusetts 02139

MAIL FROM
APR 18 1988
U.S. PAT. & TRADE MARK OFF.

Polaroid
Area Code
(617)
577-2518

April 14, 1988

Our File No. 7464

Hon. Commissioner of Patents and Trademarks
Washington, D. C. 20231

Sir:

Enclosed herewith are the petition, specification, claims, declaration, drawings, assignment and information disclosure statement in connection with an application of Woo-Jin Song and Donald S. Levinstone

for a patent for A SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION.

There is also enclosed a check to cover the cost of filing the application and recording the assignment, as follows:

Basic Fee	$340.00
Additional Fees:	
Total number of claims in excess of 20, times $12	0.00
Number of independent claims minus 3, times $34	34.00
Total Filing Fee	$374.00
Assignment Recording Fee	7.00
Total Enclosed	$381.00

It is respectfully requested that the Deposit Account of Polaroid Corporation (Account No. 16-2195) be credited with any excess filing fee or charged for any deficiency in filing fee.

Please address all communications from the Patent Office in connection with this application to Polaroid Corporation, Patent Department, 549 Technology Square, Cambridge, Massachusetts 02139.

Respectfully,

CHECK NO. 16591 ENCLOSED
IN AMOUNT OF $381.00

Edward S. Roman
Edward S. Roman
Registration No. 25,778

ESR/elt
Enclosures

Title: A SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to a system and method for electronic image enhancement by dynamic pixel transformation and, more particularly, to a system and method for enhancing electronic image information by dynamically transforming electronic information signals on a pixel-to-pixel basis.

2. Description of the Prior Art

Electronic still image cameras are becoming well known in the art. Such cameras utilize photoresponsive arrays to sense scene light and convert the sensed scene light into electronic information signals. Electronic information signals are thereafter stored on a suitable media which may include magnetic, optical or solid state storage for subsequent retrieval and viewing. It may be desirable at some point to transform the stored image defining electronic information signals to a hard copy of the scene originally recorded. Photographic media have been suggested and used for such purposes. Difficulties arise, however, as a result of differences between the wide dynamic range of the scene originally sensed and recorded and the substantially smaller dynamic range to which a photographic print may be exposed. The wide dynamic range of luminance intensities within the scene originally recorded may thus be compressed or clipped to

the substantially smaller dynamic range of the photographic print, losing detail within certain portions of the dynamic range that were otherwise visible in the original scene. Thus, it may be desirable to transform the original image defining electronic information signals in a nonlinear manner to selectively increase and/or decrease the contrast and brightness in certain portions of the scene such as those that might be brightly lit by sunlight or underlit as a result of shadows. However, no single transform function can be uniformly applied to all the image defining electronic information ~~singals~~ signals of the scene and achieve satisfying results because the lighting conditions vary across the scene.

Therefore, it is an object of this invention to provide a system and method of electronically enhancing images by dynamically increasing or decreasing contrast and brightness in selected portions of the scene that may be overlit or underlit.

It is a further object of this invention to provide a system and method of enhancing image defining electronic information signals in a dynamic manner on a pixel-by-pixel basis such that the value of each pixel is selectively transformed as a function of the average value of a plurality of pixels closely spaced about that pixel.

Other objects of the invention will be in part obvious and will in part appear hereinafter. The invention accordingly comprises a mechanism and system possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure.

SUMMARY OF THE INVENTION

A system is provided for enhancing electronic image data received in a continuous stream of electronic information signals wherein each signal corresponds to one of a plurality of succeeding pixels. The pixels col-

lectively define the image to be recorded. Means are provided for averaging the electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each of the plurality of the pixels so averaged. Means operate to thereafter select one of the plurality of different transfer functions of electronic information signals for each of the succeeding pixels. Each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing that one pixel. The electronic information signal corresponding to each pixel is subsequently transformed by the transfer function selected for that pixel. The system responds to an average electronic information signal indicative of low scene light intensity levels by transforming electronic information signals to provide a higher contrast and/or brightness to those electronic information signals corresponding to pixels having the lowest scene light intensity levels. The system also responds to an average electronic information signal indicative of high scene light intensity levels by transforming electronic information signals to provide a higher contrast and/or lower brightness to those electronic information signals corresponding to pixels having the highest scene light intensity levels.

DESCRIPTION OF THE DRAWINGS

The novel features that are considered characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with other objects and advantages thereof will be best understood from the following description of the illustrated embodiment when read in connection with the accompanying drawings wherein:

FIG. 1 is a block diagram showing the system for enhancing electronic image data in the manner of this invention;

FIG. 2 is a graphical representation showing the output electronic information signals versus the input electronic information signals;

FIG. 3 is a graphical representation showing the variation of gamma γ with different selected control parameters; and

FIG. 4 is a block diagram showing in substantially more detail a system for enhancing electronic image data of this invention in the manner of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In electronic image processing it is desirable to adjust the image contrast automatically to produce more detail in both the bright and dark areas of a scene that is recorded. The image enhancing system and method of this invention operates to both lighten the dark regions of a scene and darken the light regions of a scene by enhancing contrast to improve the detail visibility that would otherwise be lost when the electronic image signals are converted to a hard copy reproduction. Toward that end, the system and method of this invention operates to continuously enhance electronic image data received in a continuous stream of electronic information signals, each signal of which corresponds to one of the plurality of succeeding pixels which collectively define the recorded image.

Referring now to FIG. 1, there is shown a block diagram for the system of this invention in which a continuous stream of electronic information signals each corresponding to one of a plurality of succeeding pixels from the recorded image are received at terminal Y_{input}. The electronic information signals input at terminal Y_{input} may be derived in a well-known manner by

a two-dimensional photosensitive array or sensor (not shown) which may comprise a high resolution charge coupled device (CCD) or charge injection device (CID). The sensor receives image scene light in any well-known manner by way of an objective lens and shutter (also not shown). The image sensing array comprises a plurality of image sensing elements or pixels preferably arranged in a two-dimensional area array wherein each image sensing pixel converts the incident image defining scene light rays into a corresponding analog electronic information signal value. Preferably, the image sensing pixels are arranged in columns and rows as is well known in the art. As will be readily understood, image sensing arrays, particularly for sensing still images, preferably comprise a large number of image sensing elements or pixels in the order of 500,000 or greater.

The two-dimensional photosensitive arrays may also be overlayed with any one of a variety of different well-known filter patterns so that each pixel provides an electronic information signal value corresponding to a particular color. For instance, the columns of the two-dimensional photosensitive array may be overlayed with any one of a red, green or blue filter stripe arranged in a repeating fashion across the face thereof. The electronic information signal value for each pixel in this arrangement thus corresponds to a particular color.

The electronic information signal values retrieved from the photosensitive array in this manner are preferably converted to luminance (Y) and chrominance, e.g., (R-Y and B-Y) signal values. For the case where the two-dimensional photosensitive array is overlayed with red, green and blue filters, the luminance electronic information signals are preferably determined by the following relationship: $Y = 0.30R + 0.59G + 0.11B$ as is well known in the television art. The analog luminance

electronic information signal values for each pixel element of the photosensitive array for the example herein described are digitized to an 8-bit binary number so as to have a dynamic integer range of from 0 - 255 within which range are 256 intensity levels and a maximum luminance value of Y_{MAX} = 255. The electronic image detection and processing herein described so far will be recognized as being conventional and well known in the art.

The image defining electronic information signals derived in the above-described manner and preferably comprising digitized luminance signals are thereafter subjected to a gain control function which may be automatic as is well known in the art before being directed to input terminal Y_{input} of the block diagram of FIG. 1. The image defining luminance electronic information signals are thereafter averaged for selected pluralities of pixels by an averager 12. The averager 12 may comprise a low pass filter as is well known in the art which operates to provide an average value electronic information signal Av corresponding to the average luminance values for a selected window or plurality of pixels that continuously changes in correspondence with each succeeding pixel value to be enhanced. Alternatively, the averager may comprise a block average in which a selected group or block of pixel values is averaged to provide one average value electronic information signal Av in correspondence with each pixel value of that group to be enhanced. Succeeding groups of pixel values are thereafter averaged. In the preferred mode, the selected groups of pixels are preferably selected in two dimensions from the photosensitive array.

Both low pass filtering and block averaging require a buffer memory to hold the selected groupings of pixel values for averaging as is well known in the art. The low pass filter method results in a continuing change

in the average value of the electronic information signal Av for each succeeding pixel thereby providing a more accurate determination of average values for selecting the appropriate transfer function in the manner of this invention to be described. However, as will be well understood, the low pass filtering technique requires a substantially increased computational capacity in comparison to block averaging; and, therefore, block averaging, although not as highly selective as low pass filtering, may be preferred in image enhancing applications where reduced computational capacity is desired. Low pass filtering and block averaging are both well-known techniques in the electronic arts and therefor need not be described in any further detail herein.

The average value for the image defining luminance electronic information signal (Av) is thereafter provided to a gamma determining circuit 14 which determines gamma as a function of the average value input thereto in accordance with the following relationship:

$$\gamma = (1 + C)^{(Av/M-1)}$$

In the above relationship M for this example is selected to be the center value of the dynamic range of the electronic information signals. As was previously stated, the electronic signal values for this example comprise 8-bit binary numbers having a dynamic range of 256. Thus, for this example, M = 128. However, it will be readily understood that M may be selected to be any value within the dynamic range of the electronic information signals depending upon where the least image enhancement is desired. Thus, for the case where M is selected to be at the center of the dynamic range, image enhancement will have the greatest effect near the ends of the dynamic range and the least effect toward the center of the dynamic range. Selecting the value of M to be closer to the high end of the dynamic range will decrease the

effective image enhancement provided at that end by the system and method of this invention.

C is a control parameter selected in the manner of this invention to vary the amount of image enhancement that may be provided by the system and method of this invention in a manner to be more fully described in the following discussion.

The value of gamma is thereafter directed to a transfer function imposing circuit 16 which operates to impose the following transfer function on the image defining luminance electronic information signals (Y) received at input terminal Y_{input} and corresponding to each one of the succeeding pixels which collectively define the recorded image.

$$Y_{out} = Y_{MAX}(Y_{in}/Y_{MAX})^{\gamma}$$

Y_{MAX} equals the highest value of the dynamic range for the electronic information signals or 255 for the example herein described. Y_{out} equals the image defining luminance electronic information signal transformed in the manner of this invention to provide an enhanced image. As is now readily apparent, it is selected for the image defining luminance electronic information signal for each pixel as a function of a local average of image defining luminance electronic information signals for a select group or plurality of pixels closely spaced about the pixel value being enhanced or transformed. Thus, gamma γ changes continuously in correspondence with the average values from the continuous stream of succeeding image defining luminance electronic information signals so that each image defining luminance electronic information signal is enhanced or transformed by a selected one of a plurality of different transfer functions.

Referring now to FIG. 2, there is shown a graphical representation of the various transfer functions that are imposed by the transfer function circuit 16 as a

function of the variation in gamma γ. For the example as shown in FIG. 2, the control parameter C is selected to equal 1 and thus it can be seen that gamma γ has a variation of from 0.5 to 2. For instance, in the situation where the average value of the image defining luminance electronic signals is high and approaches the maximum value of the dynamic range which in this example equals 255 and is indicative of a portion of the image that is extremely bright, it can be seen that gamma γ equals 1 + C or as in the case where C = 1, gamma γ = 2 as shown in the diagram of FIG. 2. The slope of the transfer function as is readily apparent for the situation where gamma γ = 2 becomes quite steep at the high end of the dynamic range (B_{in}, B_{out}) thereby providing a higher contrast to those image defining luminance electronic information signals corresponding to pixels having the highest scene light intensity levels. The slope of the transfer function for γ = 2 decreases significantly at the low end of the dynamic range (A_{in}, A_{out}) thereby providing a lower contrast to those image defining luminance electronic information signals corresponding to pixels having the lowest scene light intensity levels. Since M is selected to be at the center of the dynamic range, it can be seen that the slope of the transfer function at the center of the dynamic range most closely approximates that of a straight line thereby providing the least effect on the output signal for pixels having intensity levels near the center of the dynamic range.

Conversely, in the situation where the average values of the image defining luminance electronic information signals are low approaching 0 indicative of localized areas of low scene light intensity levels, then gamma γ = 1 divided by 1 + C which equals 0.5 in the case where C = 1. The transfer function imposed by the transfer function circuit 16 in the case where gamma γ

equals 0.5 is shown graphically in FIG. 2 as comprising a substantially steep slope in the areas (A_{in}, A_{out}) where the image defining luminance electronic information signal values are low. Thus, the transfer function in this case where gamma γ equals 0.5 operates to transform the image defining luminance electronic information signals to provide a high contrast to those electronic information signals corresponding to pixels having the lowest scene light intensity levels. The slope of the transfer function for γ = 0.5 decreases significantly at the high end of the dynamic range (B_{in}, B_{out}) thereby providing a lower contrast to those image defining luminance electronic information signals corresponding to pixels having the highest scene light intensity levels. Again, since M is selected to be at the center of the dynamic range, it can be seen that the slope of the transfer function at the center of the dynamic range most closely approximates that of a straight line thereby providing the least effect on the output signal for pixels having intensity levels near the center of the dynamic range. It can be seen that the transfer function imposed by the transfer function circuit 16 can have any intermediate number of transfer functions shown between the extreme end transfer functions where gamma equals 0.5 or 2.0 and that all of the transfer functions are operative for the full extent of the input dynamic range so as not to clip the input signal values.

In the situation where the average value for the image defining luminance electronic information signal values corresponds to the intermediate value of the dynamic range, gamma γ = 1 and the transfer function becomes a straight line to provide a one-to-one relationship between the input and output electronic information signals with no localized increase in contrast as provided by the other transfer functions where gamma γ is either greater or less than 1. Thus, in this manner in

a situation where a scene may have localized dark or bright areas, there may be provided a localized increase in the contrast to those areas to make visible details that otherwise would be lost. The transfer functions vary in correspondence with the variation in the local average scene light intensity levels so as to apply the increased contrast selectively to those light or dark portions of the scene where details are otherwise obscured.

Referring now to FIG. 3, there is shown a graphical representation of the variation in gamma γ as a function of the variation of the control parameter C. Thus, it can be seen that for a control parameter C value of 1 gamma γ varies from 0.5 to 2. If the control parameter C is selected to be 0, gamma γ remains constant at 1. Although for a typical imaging application which requires dynamic range compression, it may be satisfactory to select the control parameter C to equal 1 thereby achieving an extreme variation in gamma from 2 to 0.5, it may be desirable to increase the amount of localized contrast thereby selecting values of the control parameter C greater than 1.

Referring now to FIG. 4 where like numerals reference previously discussed components, there is shown a circuit diagram for implementing a transfer function as described in connection with FIG. 1. The aforementioned transfer function may be converted to the following relationship by taking the logarithm on both sides of the aforementioned equation.

$$\log Y_{out} = \log Y_{MAX} + \gamma (\log Y_{in} - \log Y_{MAX})$$

Similarly, the relationship for determining gamma can also be rewritten as follows:

$$\log \gamma = (Av/M-1)[\log(1+C)]$$

These relationships can be implemented as shown by the circuit of FIG. 4. The average value of the image defining luminance electronic information signal is first

AAL 12

directed to a multiplier circuit 18 where the signal is multiplied by 1/M where M equals one-half the dynamic range of the electronic information signals as previously discussed. The output from the multiplier circuit 18, in turn, is directed to a combining circuit 20 which operates to add a negative 1 to the output from the multiplier circuit 18. The control parameter C is directed to a combiner circuit 22 which operates to add a positive 1 thereto. The output from the combiner circuit 22, in turn, is directed to a log circuit 24 which provides the logarithmic value for the C + 1 input thereto. The output from the logarithmic circuit 24, in turn, is multiplied by the output from the combining circuit 20 by a multiplier circuit 26. The output from the multiplier circuit 26, in turn, is directed to an antilogarithmic determining circuit 28 which operates utilizing a lookup table to provide the antilogarithm creating the value of gamma γ.

The image defining luminance electronic information signal for each pixel, in turn, is directed to a logarithm determining circuit 30 in the transfer function circuit 16. The output from the logarithm determining circuit 30, in turn, is directed to a combiner circuit 32 which operates to subtract therefrom the logarithm for the maximum dynamic range of the electronic information signals. The output from the combiner 32, in turn, is multiplied by multiplier circuit 34 by the value of gamma γ received from the antilogarithm determining circuit 28. The output from the multiplier 34, in turn, is directed to a combiner circuit 36 for addition to the logarithm of the maximum dynamic range of the electronic information signals. The output from the combiner circuit 36, in turn, is directed to an antilogarithm determining circuit 38 to provide the transformed image defining luminance electronic information signals Y_{out} as shown. Thus, in this manner, gamma γ is determined continuously

in accordance with the relationship as shown by the block diagram of FIG. 1 in a simple and convenient manner utilizing multiplication circuits, combining circuits, logarithm determining circuits, and antilogarithm determining circuits as shown in Fig. 4. In like manner, the transfer function continuously varied in accordance with the selection of gamma may also be imposed continuously in a simple and convenient manner by circuitry comprising a logarithm determining circuit, combining circuits, multiplication circuit, and an antilogarithm determining circuit. Thus, in this manner localized dynamic contrast enhancement can be provided as a function of dynamic gamma transformation on a pixel-by-pixel basis.

Thus, the system and method of this invention provides for enhancing electronic image data in a manner involving a relatively small number of computations that can be easily calculated in a continuous manner. All of the transfer functions that can be invoked are of a continuous nature without any sharp discontinuities that could otherwise result in undesirable artifacts appearing in the final image. In addition, as previously mentioned, none of the transfer functions operate to clip any portion of the incoming electronic information signal, thus resulting in the entire dynamic range of the incoming signal being transformed.

Other embodiments of the invention including additions, subtractions, deletions and other modifications of the preferred disclosed embodiments of the invention will be obvious to those skilled in the art and are within the scope of the following claims.

Case 14

7464

What is claimed is:

SUB A1 1. A system for continuously enhancing electronic image data received in a continuous stream of electronic information signals, each signal corresponding to one of a plurality of succeeding pixels which collectively define an image, said system comprising:

means for averaging electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels so averaged; and

means for selecting one of a plurality of different transfer functions for the electronic information signal for each of the succeeding pixels in a manner whereby each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing said one pixel and for subsequently transforming the electronic information signal corresponding to each pixel by the transfer function selected for that pixel.

2. The system of claim 1 wherein said selecting and transforming means includes means responsive to an average electronic information signal indicative of low scene light intensity levels for transforming the electronic information signals to provide a higher contrast to those electronic information signals corresponding to pixels having the lowest scene light intensity levels and is further responsive to an average electronic information signal indicative of high scene light intensity levels for transforming the electronic information signals to provide a higher contrast to those electronic information signals corresponding to pixels having the highest scene light intensity levels.

17

3. The system of claim 2 wherein said selecting and transforming means further operates to select said transfer function as a function of the ratio of the value of the average electronic information signal to the dynamic range of the electronic information signals such that the ratio increases in correspondence with the increase in the value of the average electronic information signal.

~~4~~ 3. The system of claim ~~3~~ 2 wherein said selecting and transforming means further operates to select said transfer function as a function of a determined constant whose value corresponds to the amount of contrast provided in those areas of higher contrast provided by said select transfer function.

~~5~~ 4. The system of claim ~~4~~ 3 wherein said selecting and transforming means further operates to determine the select transfer function as a function of the determination of gamma (γ), said selecting and transforming means including means for determining gamma (γ) in accordance with the relationship

$$\gamma = (1 + C)^{(Av/M-1)}$$

where C equals said determined constant, Av equals the average electronic information signal value and M equals a select proportionate value of the dynamic range of the electronic information signals.

~~6~~ 5. The system of claim ~~5~~ 4 wherein said transforming means transforms the electronic information signal of each pixel in accordance with the relationship

$$Y_{out} = Y_{MAX}(Y_{in}/Y_{MAX})^{\gamma}$$

where Y_{in} equals the value of the electronic information signal of the pixel to be enhanced, Y_{out} equals the enhanced value of the input electronic information signal and Y_{MAX} equals the highest value of the dynamic range for the electronic information signals.

SUBA2

7. A system for enhancing electronic image data received in a continuous stream of electronic information signals each signal corresponding to one of a plurality of succeeding pixels which collectively define an image, said system comprising:

means for averaging electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels so averaged;

means for dividing each of the average electronic information signals corresponding to each pixel by a value M corresponding to a select proportionate value of the dynamic range of said electronic information signals;

first means for subtracting 1 from each of the electronic information signals output by said dividing means;

first means for adding a select control parameter and 1;

first means for determining the logarithm of the output from said first adding means;

first means for multiplying the output from said first logarithm determining means by the output from said first subtracting means;

first means for determining the antilogarithm of the output from said first multiplying means;

second means for determining the logarithm for each of the continuous streams of electronic information signals;

second means for subtracting the logarithm for a value corresponding to the maximum value of the electronic information signals from the output of said second logarithm determining means;

second means for multiplying the output of said first antilogarithm determining means by the output from said second subtracting means;

second means for adding the logarithm of the value corresponding to the maximum value of the electronic information signals to the output from said second multiplying means; and

second means for determining the antilogarithm of the output from said second adding means to provide an enhanced output signal value.

8. A method for continuously enhancing electronic image data received in a continuous stream of electronic information signals each signal corresponding to one of a plurality of succeeding pixels which collectively define an image, said method comprising the steps of:

averaging the electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels;

selecting one of a plurality of different transfer functions for the electronic information signal for each of the plurality of succeeding pixels in a manner whereby each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing said one pixel; and

transforming the electronic information signal corresponding to each pixel by the transfer function selected for that pixel.

8 ~~9~~. The method of claim 7 ~~8~~ wherein the transfer function is selected: in response to an average electronic information signal indicative of low scene light intensity levels to provide a higher contrast to those electronic information signals corresponding to pixels having the lowest scene light intensity levels and in response to an average electronic information signal indicative of high scene light intensity levels to provide

a higher contrast to those electronic information signals corresponding to pixels having the highest scene light intensity levels.

10. The method of claim 9 wherein said transfer function is selected further as a function of the ratio of the value of the average electronic information signal to a select proportionate value of the dynamic range of the electronic information signals such that the ratio increases in correspondence with the increase in the value of the average electronic information signal.

~~11~~ 9. The method of claim ~~10~~ 8 wherein said transfer function is selected further as a function of a determined constant wherein increasing the value of said constant operates to increase the contrast in those areas of higher contrast provided by said select transfer function.

~~12~~ 10. The method of claim ~~11~~ 9 wherein said transfer function is selected as a function of the determination of gamma (γ) and gamma (γ) is determined for each pixel in accordance with the relationship

$$\gamma = (1 + C)^{(Av/M-1)}$$

where C equals said determined constant, Av equals the average electronic information signal value and M equals said value for one-half the dynamic range of the electronic information signals.

~~13~~ 11. The method of claim ~~12~~ 10 wherein said select transfer function for the electronic information signal of each pixel comprises the relationship

$$Y_{out} = Y_{MAX}(Y_{in}/Y_{MAX})^{\gamma}$$

where Y_{in} equals the value of the electronic information signal of the pixel to be enhanced, Y_{out} equals the enhanced value of the input electronic information signal and Y_{MAX} equals the highest value of the dynamic range for the electronic information signals.

12

~~14~~. A method for enhancing electronic image data received in a continuous stream of electronic information signals each signal corresponding to one of a plurality of succeeding pixels which collectively define an image, said method comprising the steps of:

averaging the electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels;

dividing each of the average electronic information signals corresponding to each pixel by a value M corresponding to a select proportionate value of the dynamic range of said electronic information signals;

subtracting 1 from each of the electronic information signals previously divided by the value M to provide a first intermediate signal value;

selecting a control parameter C as a function of the amount of image enhancement to be applied;

adding 1 to the control parameter C;

determining the logarithm of the control parameter C plus 1;

multiplying the logarithm of the control parameter C plus 1 by said first intermediate signal value to provide a second intermediate signal value;

determining the antilogarithm of the second intermediate signal value;

determining the logarithm for each of the continuous streams of electronic information signals;

subtracting from the previously determined logarithm for each of the continuous streams of electronic information signals the logarithm for a value corresponding to the maximum value of the electronic information signals to provide a third intermediate signal value;

multiplying the antilogarithm of the second intermediate signal value by the third intermediate signal value to provide a fourth intermediate signal value;

adding the logarithm of the value corresponding to the maximum value of the electronic information signals to the fourth intermediate signal value to provide a fifth intermediate signal value; and

determining the antilogarithm of the fifth intermediate signal value to provide an enhanced output signal value.

~~15~~ 13. The method of claim ~~14~~ 12 wherein said image enhancement operates to increase image contrast locally in areas of pixels having low contrast and said control parameter C is determined as a function of the amount of local contrast variation to be provided.

7464

Title: A SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION

ABSTRACT OF THE DISCLOSURE

A system and method are provided for continuously enhancing electronic image data received in a continuous stream of electronic information signals wherein the electronic information signal corresponding to each pixel of the image recorded is selectively transformed as a function of the average value of electronic information signals for a select plurality of pixel values in the immediate area of the pixel value being transformed. The electronic information signal transformations are provided on a pixel-by-pixel basis to increase contrast in localized areas that may be either exceptionally light or dark as a result of varying scene lighting conditions.

7464

DECLARATION FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled A System and Method for Electronic Image Enhancement by Dynamic Pixel Transformation, the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim the benefit under Title 35, United States Code, §120, of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a), which occurred between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application;

None

(Application Serial No.)	(Filing Date)	(Status: patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status: patented, pending, abandoned)

30

I hereby appoint Edward S. Roman, Reg. No. 25,778 c/o Polaroid Corporation, Patent Department, 549 Technology Square, Cambridge, Massachusetts 02139, my attorney(s) with full power of substitution, and revocation, to prosecute this application, to make alterations and amendments therein, to receive the Letters Patent, and to transact all business in the Patent Office connected therewith.

Please address all correspondence to Polaroid Corporation, Patent Department, 549 Technology Square, Cambridge, Massachusetts 02139.

Direct calls to: Edward S. Roman at (617) 577-2518.

FORM A

7464

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of sole or first inventor Woo-Jin Song

Inventor's signature Woo-Jin Song

Date 4/12/88

Residence 5509 Stearns Hill Road, Waltham, MA 02154
Citizenship Republic of Korea
Post Office Address same as above

Full name of second joint inventor, if any
Donald S. Levinstone

Second Inventor's Signature Donald Levinstone

Date 4/14/88

Residence 15 Taft Avenue, Lexington, MA 02173
Citizenship U.S.
Post Office Address same as above

Full name of third joint inventor, if any
NONE

Third Inventor's Signature

Date

Residence
Citizenship
Post Office Address

Full name of fourth joint inventor, if any

Fourth Inventor's Signature

Date

Residence
Citizenship
Post Office Address

As Original Filed

SP 7464 ESR SHEET 1 OF 2

18

FIG 1

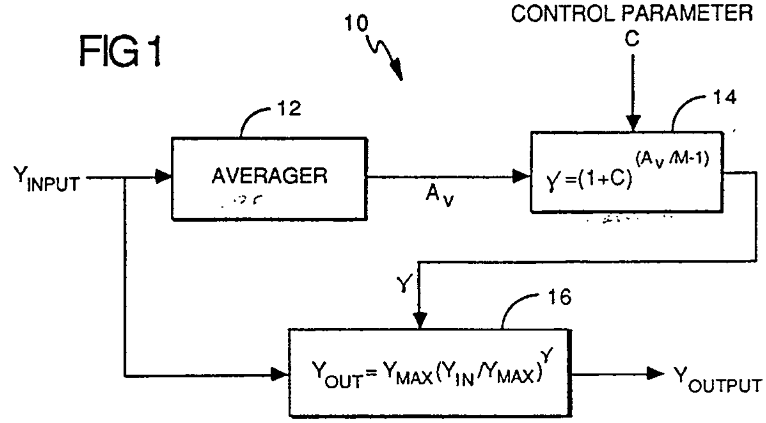
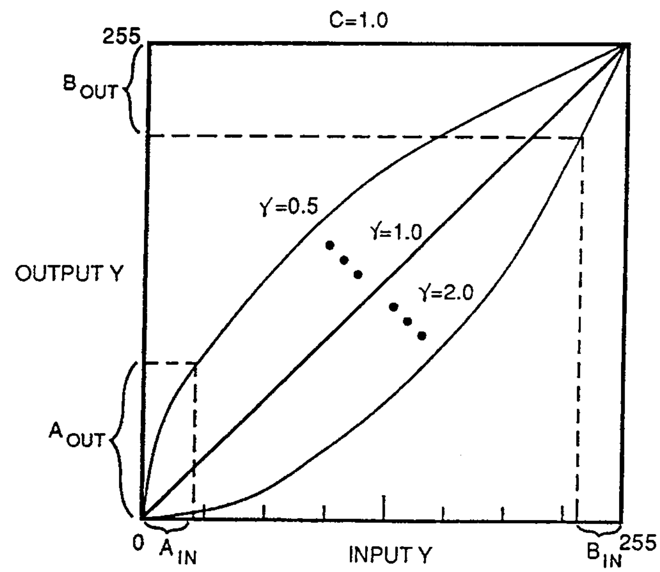


FIG 2



As Original Filed

CASE 7464 ESR SHEET 2 of 2

18297

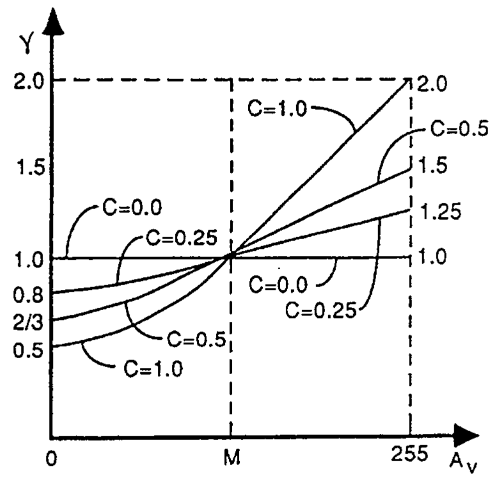


FIG 3

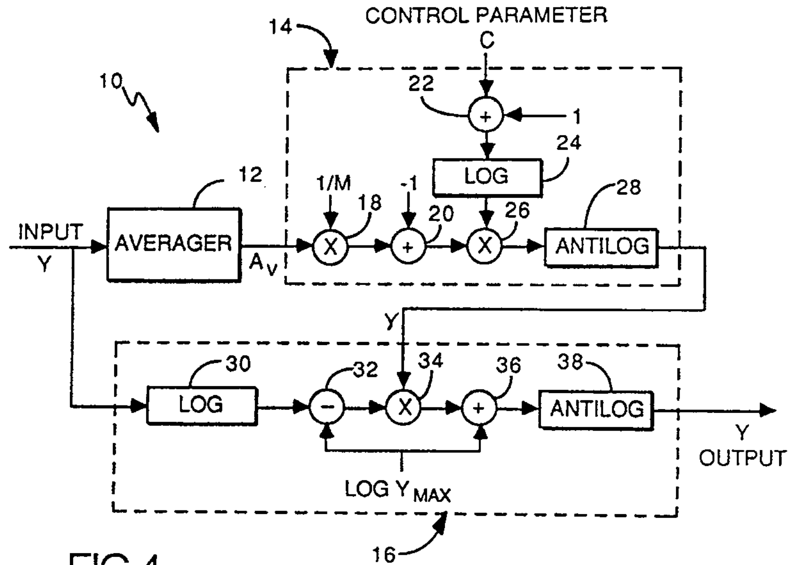


FIG 4

FORM PTO-875 (Rev. 3-83)

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE

PATENT APPLICATION FEE DETERMINATION RECORD

SERIAL NO. 182-987

FILING DATE 4-18-88

APPLICANT (FIRST NAMED) Woo-Jin Song

CLAIMS AS FILED - PART I

FOR	NO. FILED	NO. EXTRA	SMALL ENTITY RATE	SMALL ENTITY FEE		OTHER THAN A SMALL ENTITY RATE	OTHER THAN A SMALL ENTITY FEE
BASIC FEE				$170	OR		$340
TOTAL CLAIMS	15 -20 =	*	x6	$	OR	x12	$
INDEP CLAIMS	4 -3 =	* 1	x17	$	OR	x34	$34
MULTIPLE DEPENDENT CLAIM PRESENT			x55	$	OR	x110	$
			TOTAL	$	OR	TOTAL	$374

* If the difference in col. 1 is less than zero, enter "0" in col. 2

CLAIMS AS AMENDED - PART II

AMENDMENT A	(1) CLAIMS REMAINING AFTER AMENDMENT		(2) HIGHEST NO. PREVIOUSLY PAID FOR	(3) PRESENT EXTRA	SMALL ENTITY RATE	ADDIT. FEE		OTHER THAN A SMALL ENTITY RATE	ADDIT. FEE
TOTAL	*	MINUS	**	=	5	$	OR	10	$
INDEP	*	MINUS	***	=	15	$	OR	30 =	$
FIRST PRESENTATION OF MULTIPLE DEP. CLAIM					50	$	OR	100 =	$
					TOTAL ADDIT. FEE	$	OR	TOTAL	$

AMENDMENT B	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NO. PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE	ADDIT. FEE		RATE	ADDIT. FEE
TOTAL	*	MINUS	**	=	5	$	OR	10	$
INDEP	*	MINUS	***	=	15	$	OR	30	$
FIRST PRESENTATION OF MULTIPLE DEP. CLAIM					50	$	OR	100	$
					TOTAL ADDIT. FEE	$	OR	TOTAL	$

AMENDMENT C	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NO. PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE	ADDIT. FEE		RATE	ADDIT. FEE
TOTAL	*	MINUS	**	=	5 =	$	OR	10	$
INDEP	*	MINUS	***	=	15 =	$	OR	30 =	$
FIRST PRESENTATION OF MULTIPLE DEP. CLAIM					50 =	$	OR	100 =	$
					TOTAL ADDIT. FEE	$	OR	TOTAL	$

* If the entry in Col. 1 is less than the entry in Col. 2, write "0" in Col. 3.
** If the "Highest No. Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest No. Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest No. Previously Paid For" (Total or Indep.) is the highest number found in the appropriate box in Col. 1.

PTO-1130
(REV. 8-87)

PALM III APPLICATION FILE DATA CODING SHEET

U.S. DEPARTMENT OF COMMERCE–PATENT & TM OFFICE

PREPARED BY M. Balli
DATE 4-18-88

FORMAT NO. 2 Serial No.	TYPE APPL	FILING DATE (Month Day Year)	SPECIAL HANDLING	GROUP ART UNIT	CLASS	SHEETS OF DRAWINGS	ASGT?	TOTAL CLAIMS	INDEPENDENT CLAIMS	SMALL ENTITY?	FILING FEE RECEIVED	SECURITY CASE?	FOREIGN LICENSE?
07 182987	1	04 18 88				2	Y	15	4	0	374	N	G

FORMAT NO. 3 ATTORNEY DOCKET NUMBER (12 spaces): 7464

Atty.'s Reg. Nos. ☐ APPL. PAPERS ☐ CODING SHEET

FORMAT NO. 4 Applicant's Name & Address ☐ APPL. PAPERS ☐ CODING SHEET

FORMAT NO. 5 Title of Invention ☐ APPL. PAPERS ☐ CODING SHEET

FORMAT NO. 6&7 Correspondence Address ☐ APPL. PAPERS ☐ CODING SHEET

FORMAT NO. 8

	RECORD	CONTINUITY CODE	PARENT APPLICATION SERIAL NUMBER	PARENT FILING DATE (Month Day Year)	STATUS CODE	PARENT PATENT NUMBER
	RECORD 801		0			
	RECORD 802		0			
	RECORD 803		0			
	RECORD 804		0			
	RECORD 805		0			
	RECORD 806		0			
	RECORD 807		0			
	RECORD 808		0			
☐ MORE ON SUPPLEMENTAL CODING SHEET	RECORD 809		0			
	RECORD 810		0			

FORMAT NO. 9

	RECORD	COUNTRY CODE	PCT/FOREIGN APPLICATION SERIAL NUMBER	FILING DATE (Month Day Year)
	RECORD 901			
FOREIGN PRIORITY CLAIMED?	RECORD 902			
☐ YES	RECORD 903			
☐ NO	RECORD 904			
	RECORD 905			
	RECORD 906			
☐ APPLICATION PAPERS	RECORD 907			
	RECORD 908			
	RECORD 909			
☐ MORE ON SUPPLEMENTAL CODING SHEET	RECORD 910			

7464

182987

#2

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application of Woo-Jin Song and Donald S. Levinstone

For: A SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION

Cambridge, Massachusetts 02139
April 14, 1988

INFORMATION DISCLOSURE STATEMENT

Commissioner of Patents and Trademarks
Washington, D.C. 20231

Sir:

It is respectfully requested that the below-identified reference (copy enclosed) be made of record in the accompanying application.

U.S. Patent No. 4,663,667 entitled "Contrast Control Circuit" by E. K. Shenk, issued May 5, 1987, is cited for showing a contrast control circuit for use in an electronic image printing system for manually adjusting the contrast of an analog electronic information signal without changing the maximum and minimum brightness levels thereof in order to maintain the exposure of a photosensitive material. The appropriate response curve as shown in FIG. 2E may be selectively chosen by appropriately adjusting the variable contrast control potentiometer 52.

Respectfully submitted,

Edward S. Roman

Edward S. Roman
Registration No. 25,778

Enclosures:
1 U.S. Patent and Form PTO-FB-A820

Area Code
(617)
577-2518

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

SERIAL NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NO.
07/182,987	04/18/88	SONG	W 7464

POLAROID CORPORATION
PATENT DEPARTMENT
549 TECHNOLOGY SQ.
CAMBRIDGE, MA 02139

EXAMINER	
FARIS, E	
ART UNIT	PAPER NUMBER
262	3

DATE MAILED: 10/20/88

EXAMINER INTERVIEW SUMMARY RECORD

All participants (applicant, applicant's representative, PTO personnel):

(1) Groody (3) ____

(2) Roman (4) ____

Date of interview 10-18-88

James J. Groody
Supervisory Patent Examiner
Art Unit 262

Type: ☑ Telephonic ☐ Personal (copy is given to ☐ applicant ☐ applicant's representative).

Exhibit shown or demonstration conducted: ☐ Yes ☑ No. If yes, brief description: ____

Agreement ☐ was reached with respect to some or all of the claims in question. ☑ was not reached.

Claims discussed: —

Identification of prior art discussed: —

Description of the general nature of what was agreed to if an agreement was reached, or any other comments: Office will send applicants copies of PTO-892 and 1449. Office copy of action missing. Applicants will send copy back to PTO. Period for ~~~~ response will be ~~~~ restarted from mailing of PTO-892 + 1449 copies. 112 rejections to "the" logarithm etc. will be withdrawn. Examiner will set up interview.

(A fuller description, if necessary, and a copy of the amendments, if available, which the examiner agreed would render the claims allowable must be attached. Also, where no copy of the amendments which would render the claims allowable is available, a summary thereof must be attached.)

Unless the paragraphs below have been checked to indicate to the contrary, A FORMAL WRITTEN RESPONSE TO THE LAST OFFICE ACTION IS NOT WAIVED AND MUST INCLUDE THE SUBSTANCE OF THE INTERVIEW (e.g., items 1–7 on the reverse side of this form). If a response to the last Office action has already been filed, then applicant is given one month from this interview date to provide a statement of the substance of the interview.

☑ It is not necessary for applicant to provide a separate record of the substance of the interview.

☐ Since the examiner's interview summary above (including any attachments) reflects a complete response to each of the objections, rejections and requirements that may be present in the last Office action, and since the claims are now allowable, this completed form is considered to fulfill the response requirements of the last Office action.

JJG
Examiner's Signature

PTOL-413 (REV. 1-84)

ORIGINAL FOR INSERTION IN RIGHT HAND FLAP OF FILE WRAPPER

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address : COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

SERIAL NUMBER	FILING DATE	FIRST NAMED APPLICANT		ATTORNEY DOCKET NO.
07/182,987	04/18/88	SONG	W	7464

POLAROID CORPORATION
PATENT DEPARTMENT
549 TECHNOLOGY SQ.
CAMBRIDGE, MA 02139

EXAMINER	
FARIS,E.	
ART UNIT	PAPER NUMBER
262	3

DATE MAILED: 10/20/88

Please find below a communication from the EXAMINER in charge of this application.

Commissioner of Patents and Trademarks

Responsive to Communication Filed ____________ .

The enclosed is a correct copy of a reference relating to the last Office action. The correction is indicated below.

THE PERIOD FOR RESPONSE OF 3 MONTHS SET IN SAID OFFICE ACTION IS RESTARTED TO BEGIN WITH THE DATE OF THIS LETTER.

☒ Part 1 - Correct Reference Citation

PTO-892 copy

PTO-1449 copy

by E. Faris
Examiner

☐ Part 2 - Correct Reference Furnished:

____

____

by ____________
Reference Order Center

enc.

PTOL-316 (rev. 6/78)

Status
041

MAIL ROOM
OCT 24 1988
PAT. & TRADEMARK OFF.
7464

003

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application of W. Song et al.) Group Art Unit 262
Serial No. 182,987) Examiner: E. Faris
Filed: April 18, 1988)
For: A SYSTEM AND METHOD FOR)
ELECTRONIC IMAGE)
ENHANCEMENT BY DYNAMIC)
PIXEL TRANSFORMATION)

10/27/88

Cambridge, Massachusetts
October 20, 1988

To the Commissioner of Patents
and Trademarks
Washington, D.C. 20231

COMMUNICATION

Sir:

In response to my telephone conversation with Supervisory Patent Examiner Groody on October 18, 1988, please find enclosed a copy of the Office Action dated October 14, 1988 which Mr. Groody indicated was missing from the Office file. It is understood that a copy of form PTO-892 and copies of the cited references will be forwarded to Applicants' Attorney.

Respectfully submitted,

Edward S. Roman

Edward S. Roman
Registration No. 25,778

Enclosure
Tel. 617-577-2518

I hereby certify that this correspondence is being deposited today with the United States Postal Service as first class mail in an envelope addressed to: Commissioner of Patents and Trademarks, Washington, D.C. 20231.

Name: Edward S. Roman
Registration No. 25,778
Date: October 20, 1988

MAIL ROOM OCT 24 1988 PATENT & TRADEMARK

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address : COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

SERIAL NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NO.
07/182,987	04/18/88	SUNG W	7464

POLAROID CORPORATION
PATENT DEPARTMENT
549 TECHNOLOGY SQ.
CAMBRIDGE, MA 02139

RECEIVED
OCT 17 1988
PATENT DEPT.

EXAMINER	
FARIS, E.	
ART UNIT	PAPER NUMBER
262	2

DATE MAILED: 10/14/88

RECEIVED
OCT 2
GROUP

This is a communication from the examiner in charge of your application.

COMMISSIONER OF PATENTS AND TRADEMARKS

☒ This application has been examined ☐ Responsive to communication filed on ________ ☐ This action is made final.

A shortened statutory period for response to this action is set to expire 3 month(s), —— days from the date of this letter.
Failure to respond within the period for response will cause the application to become abandoned. 35 U.S.C. 133

Part I THE FOLLOWING ATTACHMENT(S) ARE PART OF THIS ACTION:

1. ☒ Notice of References Cited by Examiner, PTO-892.
2. ☐ Notice re Patent Drawing, PTO-948.
3. ☒ Notice of Art Cited by Applicant, PTO-1449
4. ☐ Notice of informal Patent Application, Form PTO-152
5. ☐ Information on How to Effect Drawing Changes, PTO-1474
6. ☐ ________

Part II SUMMARY OF ACTION

1. ☒ Claims 1-15 are pending in the application.

   Of the above, claims ________ are withdrawn from consideration.

2. ☐ Claims ________ have been cancelled.
3. ☐ Claims ________ are allowed.
4. ☒ Claims 1-15 are rejected.
5. ☐ Claims ________ are objected to.
6. ☐ Claims ________ are subject to restriction or election requirement.
7. ☐ This application has been filed with informal drawings which are acceptable for examination purposes until such time as allowable subject matter is indicated.
8. ☐ Allowable subject matter having been indicated, formal drawings are required in response to this Office action.
9. ☐ The corrected or substitute drawings have been received on ________. These drawings are ☐ acceptable; ☐ not acceptable (see explanation).
10. ☐ The ☐ proposed drawing correction and/or the ☐ proposed additional or substitute sheet(s) of drawings, filed on ________. has (have) been ☐ approved by the examiner. ☐ disapproved by the examiner (see explanation).
11. ☐ The proposed drawing correction, filed ________, has been ☐ approved. ☐ disapproved (see explanation). However, the Patent and Trademark Office no longer makes drawing changes. It is now applicant's responsibility to ensure that the drawings are corrected. Corrections MUST be effected in accordance with the instructions set forth on the attached letter "INFORMATION ON HOW TO EFFECT DRAWING CHANGES", PTO-1474.
12. ☐ Acknowledgment is made of the claim for priority under 35 U.S.C. 119. The certified copy has ☐ been received ☐ not been received ☐ been filed in parent application, serial no. ________ ; filed on ________.
13. ☐ Since this application appears to be in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under Ex parte Quayle, 1935 C.D. 11; 453 O.G. 213.
14. ☐ Other

PTOL-326 (Rev. 7-82) EXAMINER'S ACTION

1. Claims 3-7 and 10-15 are rejected under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention.

With respect to claim 3, there is no antecedent basis for "the ratio" (line 3), "the value" (lines 3) or "the dynamic range" (lines 4 and 5).

In claim 7, there is no antecedent basis for "the dynamic range" (line 13), "the logarithm" (line 19), "the antilogarithm" (line 24), "the logarithm" (line 26) or "the maximum value" (line 30).

In claim 10, "the ratio", "the ~~vatue~~ value" (line 3), and "the dynamic range" lack antecedent basis.

In claim 14, there is no antecedent basis for "the dynamic range" (lines 12 and 13) "the amount" (line 18), "the logarithm" (line 20), "the antilogarithm" (line 25), and "the logarithm" (line 27).

Finally, in claims 15, "the amount" lacks antecedent basis.

2. The following is a quotation of 35 U.S.C. 103 which forms the basis for all obviousness rejections set forth in this Office action:

> A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

> Subject matter developed by another person, which qualifies as prior art only under subsection (f) and (g) of section 102 of this title, shall not preclude patentability under this section where the subject matter and the claimed invention were, at the time the invention was made, owned by the same person or subject to an obligation of assignment to the same person.

3. Claims 1, 2, 8 and 9 are rejected under 35 U.S.C. 103 as being unpatentable over Okada. 4,499,349

With respect to claims 1, 2, 8 and 9, Okada discloses a video brightness control circuit having an average picture level detector 20 which averages input picture information and provides a control signal to a variable correction circuit 10. The variable correction circuit operates on the input-output signal to vary the characteristic of the input-output signal as a function of the detected average picture level detector (see Fig. 2). Okada controls the relative brightness of the video signal such that the picture areas containing most of the picture information are corrected to give greater contrast. Although, Okada does not identically disclose all the limitation as recited in claims 1, 2, 8 and 9, Okada does provide a system which attempts to achieve the same results as the applicant. Both systems show an averaging circuit and a correction circuit which use the averaged information to produce an output which follows the slopes of the curves shown in Figure 2 of the present invention and Figure 2 of Okada. Therefore, claims 1, 2, 8 and 9 would have been obvious in view of Okada.

5. Claims 3-6 and 10-13 would be allowable if rewritten to overcome the rejection under 35 U.S.C. 112 and to include all of the limitations of the base claim and any intervening claims.

6. Claims 7, 14 and 15 would be allowable if rewritten or amended to overcome the rejection under 35 U.S.C. 112.

7. Any inquiry concerning this communication or earlier communications from the examiner should be directed to A. Faris whose telephone number is (703) 557-6271.

Any inquiry of a general nature or relating to the status of this application should be directed to the Group receptionist whose telephone number is (703) 557-3321.

A. FARIS:flj

703-557-6271

10-12-88

James J. Groody
Supervisory Patent Examiner
Art Unit 262

TO SEPARATE, HOLD TOP AND BOTTOM EDGES, SNAP–APART AND DISCARD CARBON

FORM PTO-892 (REV. 3-78) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

NOTICE OF REFERENCES CITED

SERIAL NO. 182987 | GROUP ART UNIT 262 | ATTACHMENT TO PAPER NUMBER 2

APPLICANT(S) Song et al

U.S. PATENT DOCUMENTS

*		DOCUMENT NO.	DATE	NAME	CLASS	SUB-CLASS	FILING DATE IF APPROPRIATE
	A	4215294	7/80	Taggart	358	168X	
	B	4334244	6/82	Chan et al	358	166	
	C	4489349	12/84	Okada	358	168	
	D	4523230	6/85	Carlson et al	358	167	
	E	4549212	10/85	Bayer	358	167	
	F	4568978	2/86	Cosh	358	32X	
	G	4751566	6/88	Pilot	358	32	
	H						
	I						
	J						
	K						

FOREIGN PATENT DOCUMENTS

*		DOCUMENT NO.	DATE	COUNTRY	NAME	CLASS	SUB-CLASS	PERTINENT SHTS. DWG	PP. SPEC.
X	L	2312150	12/76	France	Thomson	358	164		
X	M	1605009	12/81	GB	Augustin et al	358	168		
	N								
	O								
	P								
	Q								

OTHER REFERENCES (Including Author, Title, Date, Pertinent Pages, Etc.)

R	
S	
T	
U	

EXAMINER A. Faris | DATE 10-2-88

* A copy of this reference is not being furnished with this office action. (See Manual of Patent Examining Procedure, section 707.05 (a).)

OMB No. 0651-0011 (12/31/86)

INFORMATION DISCLOSURE CITATION (Use several sheets if necessary)	ATTY. DOCKET NO. 7464/ESR	SERIAL NO. 182987
	APPLICANT Woo-Jin Song and Donald S. Levinstone	
	FILING DATE 4-18-88	GROUP 260

U.S. PATENT DOCUMENTS

EXAMINER INITIAL		DOCUMENT NUMBER	DATE	NAME	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
DF		4663667	5/87	Shenk	358	169	

FOREIGN PATENT DOCUMENTS

		DOCUMENT NUMBER	DATE	COUNTRY	CLASS	SUBCLASS	TRANSLATION YES	TRANSLATION NO

OTHER DOCUMENTS *(Including Author, Title, Date, Pertinent Pages, Etc.)*

EXAMINER: D. Faris | DATE CONSIDERED: 10-2-88

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

Form PTO-FB-A820 (also form PTO-1449)

Patent and Trademark Office - U.S. DEPARTMENT of COMMERCE

CL 26-C A. 041 11-3-88

DP 262

#6 A
Roland
12-28-88

7464

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application of W. Song et al.	) Group Art Unit 262
Serial No. 182,987	) Examiner: E. Faris
Filed: April 18, 1988	)
For: A SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION	)

Cambridge, Massachusetts
December 8, 1988

To the Commissioner of Patents
and Trademarks
Washington, D.C. 20231

AMENDMENT

Sir:

In response to the Office Actions of October 14, and October 20, 1988, Applicants amend the above-entitled application as follows:

<u>In the Claims</u>:

Please amend claim 1 as follows:

A1 cont

1. (Amended) A system for continuously enhancing electronic image data received in a continuous stream of electronic information signals, each signal <u>having a value within a determinate dynamic range of values and</u> corresponding to one of a plurality of succeeding pixels which collectively define an image, said system comprising:

15

Serial No. 182,987

means for averaging electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels so averaged; and

means for selecting one of a plurality of different transfer functions for the electronic information signal for each of the succeeding pixels in a manner whereby each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing said one pixel and for subsequently transforming the electronic information signal corresponding to each pixel by the transfer function selected for that pixel wherein said selecting and transforming means further operates to select said transfer function as a function of the ratio of the value of the average electronic information signal to the dynamic range of the electronic information signals such that the ratio increases in correspondence with the increase in the value of the average electronic information signal.

H1 conch

NP

Claim 2, line 2, change "includes means" to --is--.

Claim 2, line 8, after "and" insert --is--.

Cancel claim 3.

16

Serial No. 182,987

Claim 4, line 1, change "claim 3" to --claim 2--.

Please amend claim 7 as follows:

6 ~~7~~. (Amended) A system for enhancing electronic image data received in a continuous stream of electronic information signals each signal having a value within a determinate dynamic range of values and corresponding to one of a plurality of succeeding pixels which collectively define an image, said system comprising:

A2 cont

means for averaging electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels so averaged;

means for dividing each of the average electronic information signals corresponding to each pixel by a value M corresponding to a select proportionate value of the dynamic range of said electronic information signals;

first means for subtracting 1 from each of the electronic information signals output by said dividing means;

first means for adding a select control parameter and 1;

first means for determining the logarithm of the output from said first adding means;

Serial No. 182,987

first means for multiplying the output from said first logarithm determining means by the output from said first subtracting means;

first means for determining the antilogarithm of the output from said first multiplying means;

second means for determining the logarithm for each of the continuous streams of electronic information signals;

A2 cont

second means for subtracting the logarithm for a value corresponding to the maximum value of the electronic information signals from the output of said second logarithm determining means;

second means for multiplying the output of said first antilogarithm determining means by the output from said second subtracting means;

second means for adding the logarithm of the value corresponding to the maximum value of the electronic information signals to the output from said second multiplying means; and

second means for determining the antilogarithm of the output from said second adding means to provide an enhanced output signal value.

Please amend claim 8 as follows:

7 ~~8~~. (Amended) A method for continuously enhancing electronic image data received in a continuous stream of electronic information signals each signal having a

Serial No. 182,987

value within a determinate dynamic range of values and corresponding to one of a plurality of succeeding pixels which collectively define an image, said method comprising the steps of:

averaging the electronic information signals corresponding to selected pluralities of pixels and providing an average electronic information signal for each said plurality of pixels;

A2 concl

selecting one of a plurality of different transfer functions for the electronic information signal for each of the plurality of succeeding pixels in a manner whereby each transfer function is selected as a function of the electronic information signal for one pixel and the average electronic information signal for the select plurality of pixels containing said one pixel; and

transforming the electronic information signal corresponding to each pixel by the transfer function selected for that pixel wherein said transfer function is selected further as a function of the ratio of the value of the average electronic information signal to a select proportionate value of the dynamic range of the electronic information signals such that the ratio increases in correspondence with the increase in the value of the average electronic information signal.

Cancel claim 10.

21 [illegible]

Serial No. 182,987

Claim 11, line 1, change "claim 10" to --claim 9--.

REMARKS

The Examiner rejected claims 3 - 7 and 10 - 15 under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which Applicants regard as the invention. Claims 1, 2, 8 and 9 were also rejected under 35 U.S.C. 103 as being unpatentable over Okada. In response to these rejections, Applicants have amended claims 1, 2, 4, 7, 8, 10 and 11 and cancelled claims 3 and 10.

Claim 1 has been amended to incorporate all the limitations of dependent claim 3 which the Examiner indicated to be allowable. The recitations of claim 2 do not include any antecedents required by claim 3 and hence have not been included in the amended claim 1. Likewise, claim 8 has been amended to include all the limitations of dependent claim 10 which the Examiner also indicated to be allowable. The recitations of claim 9 also do not include any antecedents required by claim 8 and hence have not been included in the amended claim 8. Claims 1, 7 and 8 have also been amended to recite that the signals have values within a determinate dynamic range thereby obviating the Examiner's rejections based on lack of antecedent

Serial No. 182,987

basis for these terms. It is respectfully urged that the remainder of the rejections based on lack of antecedents are inappropriate.

Therefore, in the absence of more pertinent art, it is requested that claims 1, 2, 4 - 8, 9 and 11 - 15 be allowed and the subject application passed to issue.

Respectfully submitted,

Edward S. Roman
Registration No. 25,778

617-577-2518

I hereby certify that this correspondence is being deposited today with the United States Postal Service as first class mail in an envelope addressed to: Commissioner of Patents and Trademarks, Washington, D.C. 20231.

Name:
Registration No. 25,778
Date: December 8, 1988

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

SERIAL NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NO.
07/182,962	04/18/88	FONG H	7464

POLAROID CORPORATION
PATENT DEPARTMENT
549 TECHNOLOGY SQ.
CAMBRIDGE, MA 02139

EXAMINER	
FARIS, E	
ART UNIT	**PAPER NUMBER**
262	7

DATE MAILED: 01/04/89

NOTICE OF ALLOWABILITY

PART I.

1. ☒ This communication is responsive to amendment A filed on December 12, 1988.
2. ☒ All the claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice Of Allowance And Issue Fee Due or other appropriate communication will be sent in due course.
3. ☒ The allowed claims are 1, 2, 4-9, 11-15 renumbered as 1-13.
4. ☒ The drawings filed on 4/18/88 are acceptable.
5. ☐ Acknowledgment is made of the claim for priority under 35 U.S.C. 119. The certified copy has [ ] been received. [ ] not been received. [ ] been filed in parent application Serial No. ______, filed on ______.
6. ☐ Note the attached Examiner's Amendment.
7. ☐ Note the attached Examiner Interview Summary Record, PTOL-413.
8. ☐ Note the attached Examiner's Statement of Reasons for Allowance.
9. ☐ Note the attached NOTICE OF REFERENCES CITED, PTO-892.
10. ☐ Note the attached INFORMATION DISCLOSURE CITATION, PTO-1449.

PART II.

A SHORTENED STATUTORY PERIOD FOR RESPONSE to comply with the requirements noted below is set to EXPIRE THREE MONTHS FROM THE "DATE MAILED" indicated on this form. Failure to timely comply will result in the ABANDONMENT of this application. Extensions of time may be obtained under the provisions of 37 CFR 1.136(a).

1. ☐ Note the attached EXAMINER'S AMENDMENT or NOTICE OF INFORMAL APPLICATION, PTO-152, which discloses that the oath or declaration is deficient. A SUBSTITUTE OATH OR DECLARATION IS REQUIRED.
2. ☐ APPLICANT MUST MAKE THE DRAWING CHANGES INDICATED BELOW IN THE MANNER SET FORTH ON THE REVERSE SIDE OF THIS PAPER.
   a. ☐ Drawing informalities are indicated on the NOTICE RE PATENT DRAWINGS, PTO-948, attached hereto or to Paper No. ______. CORRECTION IS REQUIRED.
   b. ☐ The proposed drawing correction filed on ______ has been approved by the examiner. CORRECTION IS REQUIRED.
   c. ☐ Approved drawing corrections are described by the examiner in the attached EXAMINER'S AMENDMENT. CORRECTION IS REQUIRED.
   d. ☐ Formal drawings are now REQUIRED.

Any response to this letter should include in the upper right hand corner, the following information from the NOTICE OF ALLOWANCE AND ISSUE FEE DUE: ISSUE BATCH NUMBER, DATE OF THE NOTICE OF ALLOWANCE, AND SERIAL NUMBER.

Attachments:

- Examiner's Amendment
- Examiner Interview Summary Record, PTOL-413
- Reasons for Allowance
- Notice of References Cited, PTO-892
- Information Disclosure Citation, PTO-1449
- Notice of Informal Application, PTO-152
- Notice re Patent Drawings, PTO-948
- Listing of Bonded Draftsmen
- Other

James J. Groody
Supervisory [illegible] Examiner
Art Unit 262

PTOL-37 (REV. 2-85)

USCOMM-DC 85-3744

PTOL-85 (REV. 4-86)

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office

Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

NOTICE OF ALLOWANCE AND ISSUE FEE DUE

[illegible] CORPORATION
PATENT DEPARTMENT
[illegible] TECHNOLOGY SQ.
CAMBRIDGE, MA 02139

All communications regarding this application should give the serial *number, date of filing, name of* applicant, and batch number.

Please direct all communications to the Attention of "OFFICE OF PUBLICATIONS" unless advised to the contrary.

The application identified below has been examined and found allowable for issuance of Letters Patent. PROSECUTION ON THE MERITS IS CLOSED.

SC/SERIAL NO.	FILING DATE	TOTAL CLAIMS	EXAMINER AND GROUP ART UNIT	DATE MAILED
07/182,287	04/18/88	013	[illegible], E 262	01/04/89

First Named Applicant: [illegible]

TITLE OF INVENTION: SYSTEM AND METHOD FOR ELECTRONIC [illegible] ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION

ATTY'S DOCKET NO.	CLASS-SUBCLASS	BATCH NO.	APPLN. TYPE	SMALL ENTITY	FEE DUE	DATE DUE
[illegible]	358-168.000	[illegible]	UTILITY	NO	$560.00	04/04/89

The amount of the issue fee is specified in 37 C.F.R. 1.18. If the applicant qualified for and has filed a verified statement of small entity status in accordance with 37 C.F.R. 1.27, the issue fee is one-half the amount for non-small entities. The issue fee due printed above reflects applicant's status as of the time of mailing this notice. A verified statement of small entity status may be filed prior to or with payment of the issue fee. However, in accordance with 37 C.F.R. 1.28, failure to establish status as a small entity prior to or with payment of the issue fee precludes payment of the issue fee in the amount so established for small entities and precludes a refund of any portion thereof paid prior to establishing status as a small entity.

THE ISSUE FEE MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE as indicated above. The application shall otherwise be regarded as ABANDONED. The issue fee will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the Patent and Trademark Office. Where an authorization to charge the issue fee to a deposit account has been filed before the mailing of the notice of allowance, the issue fee is charged to the deposit account at the time of mailing of this notice in accordance with 37 C.F.R. 1.311. If the issue fee has been so charged, it is indicated above.

In order to minimize delays in the issuance of a patent based on this application, **this Notice may have been mailed prior to completion of final processing.** The nature and/or extent of the remaining revision or processing requirements may cause slight delays of the patent. In addition, **if prosecution is to be reopened, this Notice of Allowance will be vacated and the appropriate Office action will follow in due course.** If the issue fee has already been paid and prosecution is reopened, the applicant may request a refund or request that the fee be credited to a deposit account. However, applicant may request that the previously submitted issue fee be applied. If abandoned, applicant may request refund or credit to a deposit account.

In the case of each patent issuing without an assignment, the complete post office address of the inventor(s) will be printed in the patent heading and in the Official Gazette. If the inventor's address is now different from the address which appears in the application, please fill in the information in the spaces provided on PTOL-85b enclosed. If there are address changes for more than two inventors, enter the additional addresses on the reverse side of the PTOL-85b.

The appropriate spaces in the ASSIGNMENT DATA section of PTOL-85b must be completed in all cases. If it is desired to have the patent issue to an assignee, an assignment must have been previously submitted to the Patent and Trademark Office or must be submitted not later than the date of payment of the issue fee as required by 37 C.F.R. 1.334. Where there is an assignment, the assignee's name and address must be provided on the PTOL-85b to ensure its inclusion in the printed patent.

Advance orders for 10 or more printed copies of the prospective patent can be made by completing the information in Section 4 of PTOL-85b and submitting payment therewith. If use of a deposit account is being authorized for payment, PTOL-85c should also be forwarded. The order must be for at least 10 copies and must accompany the issue fee. The copies ordered will be sent only to the address specified in section 1 or 1A of PTOL-85b.

☒ Note attached communication from the Examiner.

☐ This notice is issued in view of applicant's communication filed ____________

IMPORTANT REMINDER

Patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. See 37 CFR 1.20 (e)—(j).

PATENT AND TRADEMARK OFFICE COPY

560-02-142
46,00-501

POL 85b (REV 4-86) 7164/ESR

ISSUE FEE TRANSMITTAL

U.S. Department of Commerce
Patent and Trademark Office

This form is provided in lieu of a formal transmittal and should be used for transmitting the Issue Fee. Sections 1A through 4 must be completed as appropriate.

INVENTOR'S ADDRESS CHANGE | SC SERIAL NO.
INVENTOR'S NAME
Street Address
City, State and ZIP Code
CO-INVENTOR'S NAME
Street Address
City, State and ZIP Code

☐ Check if additional changes are on reverse side

MAR 1989 TRADEMARK

MAILING INSTRUCTIONS

All further correspondence including the Issue Fee Receipt, the Patent, and advanced orders will be mailed to the addressee entered in section 1 on PTOL-85c, unless you direct otherwise by specifying the appropriate name and address in 1A below. (Note: See box 5 below for correspondence concerning maintenance fee payments.)

2A The COMMISSIONER OF PATENTS AND TRADEMARKS is requested to apply the Issue Fee to the application identified below.

Polaroid Corporation

(Signature of party in interest of record) By Edward S. Roman (Date) 3/1/89

Note. The Issue Fee will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the Patent and Trademark Office.

SC/SERIAL NO.	FILING DATE	TOTAL CLAIMS	EXAMINER AND GROUP ART UNIT		DATE MAILED
07/182,987	04/18/88	013	FARIS, E	262	01/04/89

First Named Applicant: SONG, MOO-JIN

TITLE OF INVENTION: SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION

ATTY'S DOCKET NO.	CLASS-SUBCLASS	BATCH NO.	APPLN. TYPE	SMALL ENTITY	FEE DUE	DATE DUE
7164	358-148.000	F19	UTILITY	NO	$560.00	04/04/89

1A Further correspondence to be mailed to the following:

POLAROID CORPORATION
PATENT DEPARTMENT
549 TECHNOLOGY SQUARE
CAMBRIDGE, MASS. 02139

2B For printing on the patent front page, list the names of not more than 3 registered patent attorneys or agents OR, alternatively, the name of a firm having as a member a registered attorney or agent. If no name is listed, no name will printed.

1 Edward S. Roman
2
3

DO NOT USE THIS SPACE

040	03/10/89	182987	1 142	500.00	CK
040	03/10/89	182987	1 501	45.00	CK
040	03/10/89	182987	1 142	60.00	CK

3. ASSIGNMENT DATA (print or type)

A. (1) ☐ This application is NOT assigned.
(2) ☒ Assignment previously submitted to the Patent and Trademark Office
(3) ☐ Assignment submitted herewith.

B. For Printing On The Patent: (Unless an assignee is identified below, no assignee data will appear on the patent. Inclusion of assignee data below is only appropriate when an assignment has been previously submitted to the PTO or is submitted herewith. Completion of this form is NOT a substitute for filing of an assignment as required by 37 C.F.R. 1.334).

(1) NAME OF ASSIGNEE: Polaroid Corporation

(2) ADDRESS: (City & State or Country) Patent Dept., Cambridge, Mass. 02139

(3) STATE OF INCORPORATION, IF ASSIGNEE IS A CORPORATION: Delaware

4. The following fees are enclosed:
☒ Issue fee ☒ Advanced order ☐ Assignment recording

The following fees should be charged to deposit acc. no. ____________
(PTOL-85c or additional copy of PTOL-85b must be enclosed)
☐ Issue fee ☐ Assignment recording
☐ Advanced order ☐ Any additional fees due

Number of advanced order copies requested. 30
(must be for 10 or more copies)

5. All correspondence relating to maintenance fees will be addressed to the correspondence address unless a separate "Fee Address" is provided to the Patent and Trademark Office (37 C.F.R. 1.363). A "Fee Address" may be submitted by the owner of record with the payment of the issue fee or thereafter by using form PTO-1537.

TRANSMIT THIS FORM WITH FEE

7464

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application of Woo-Jin Song et al.)	Group Art Unit 262
Serial No. 182,987)	Examiner E. Faris
Filed: April 18, 1988)	
For: SYSTEM AND METHOD FOR ELECTRONIC IMAGE ENHANCEMENT BY DYNAMIC PIXEL TRANSFORMATION)	

Cambridge, Massachusetts
March 1, 1989

CERTIFICATE OF MAILING

Commissioner of Patents and Trademarks
Washington, D.C. 20231

Sir:

I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Commissioner of Patents and Trademarks, Box Issue Fees, Washington, D.C., on March 1, 1989.

Respectfully submitted,

Edward S. Roman
Edward S. Roman
Registration No. 25,778

Enclosures:
PTOL-85b and fee

Tel. No.: 617-577-2518

FIG 1

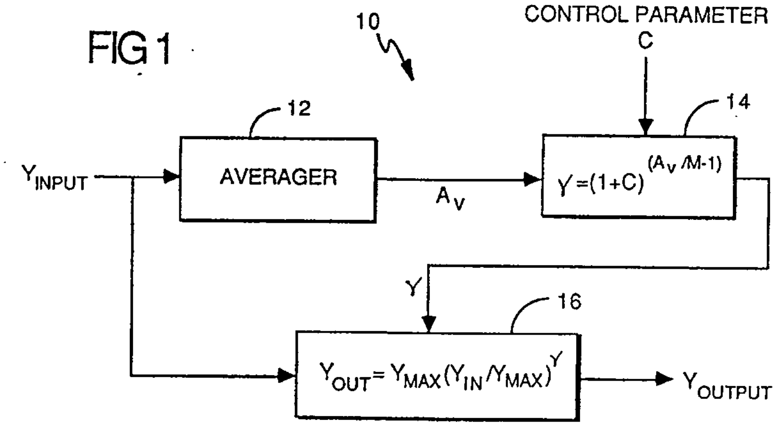
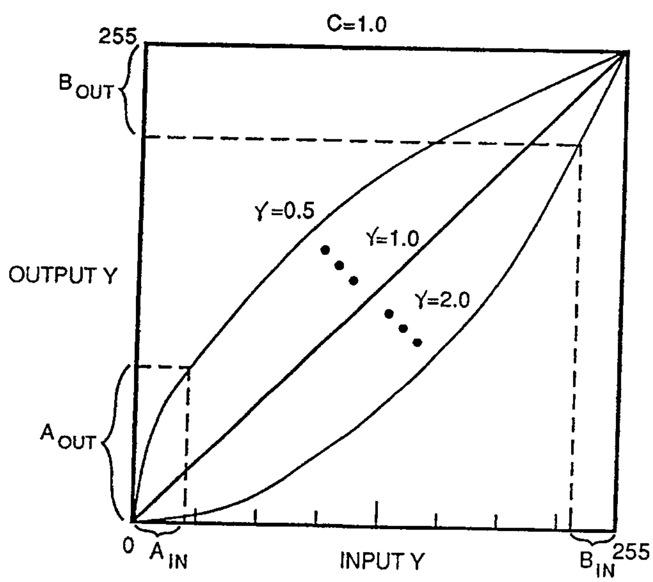
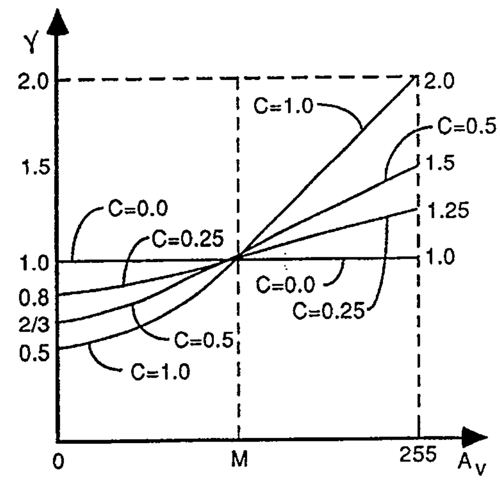

10
CONTROL PARAMETER
C
12
14
Y_{INPUT}
AVERAGER
A_V
$\gamma=(1+C)^{(A_V/M-1)}$
γ
16
$Y_{OUT}=Y_{MAX}(Y_{IN}/Y_{MAX})^{\gamma}$
Y_{OUTPUT}

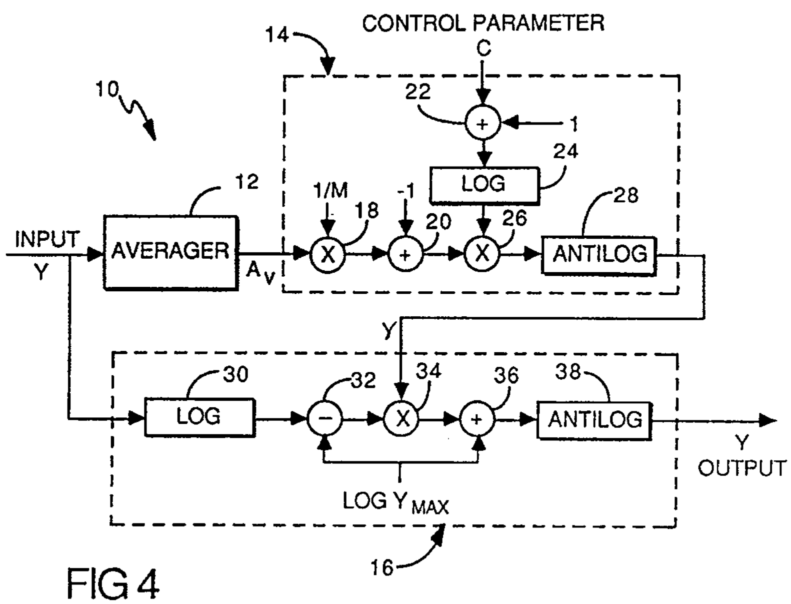
FIG 2


C=1.0
255
B_{OUT}
$\gamma=0.5$
$\gamma=1.0$
$\gamma=2.0$
OUTPUT Y
A_{OUT}
0
A_{IN}
INPUT Y
B_{IN}
255



Y
2.0
1.5
1.0
0.8
2/3
0.5
C=1.0
C=0.5
1.5
1.25
1.0
2.0
C=0.0
C=0.25
C=0.0
C=0.25
C=0.5
C=1.0
0
M
255
A_V

FIG 3



CONTROL PARAMETER
C
14
10
22
1
24
LOG
12
1/M
-1
18
20
26
28
INPUT
Y
AVERAGER
A_V
ANTILOG
Y
30
32
34
36
38
LOG
ANTILOG
Y
OUTPUT
LOG Y_{MAX}
16

FIG 4

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
ASSISTANT SECRETARY AND COMMISSIONER
OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

CHANGE OF ADDRESS/POWER OF ATTORNEY

LOCATION 9200 SERIAL NUMBER 07182987 PATENT NUMBER 4829381

THE CORRESPONDENCE ADDRESS HAS BEEN CHANGED TO CUSTOMER # 20349

THE PRACTITIONERS OF RECORD HAVE BEEN CHANGED TO CUSTOMER # 20349

THE FEE ADDRESS HAS BEEN CHANGED TO CUSTOMER # 20349

ON 11/27/98 THE ADDRESS OF RECORD FOR CUSTOMER NUMBER 20349 IS:

POLAROID CORPORATION
PATENT DEPARTMENT
784 MEMORIAL DRIVE
CAMBRIDGE MA 02139

AND THE PRACTITIONERS OF RECORD FOR CUSTOMER NUMBER 20349 ARE:

24359	24359	25173	25173	25778	25778	25937	25937	26378	26378
29629	29629	33740	34442	34442	35344	36780	36780	40049	40256
42562	42562								

PTO INSTRUCTIONS: PLEASE TAKE THE FOLLOWING ACTION WHEN THE CORRESPONDENCE ADDRESS HAS BEEN CHANGED TO CUSTOMER NUMBER: RECORD, ON THE NEXT AVAILABLE CONTENTS LINE OF THE FILE JACKET, 'ADDRESS CHANGE TO CUSTOMER NUMBER'. LINE THROUGH THE OLD ADDRESS ON THE FILE JACKET LABEL AND ENTER ONLY THE 'CUSTOMER NUMBER' AS THE NEW ADDRESS. FILE THIS LETTER IN THE FILE JACKET. WHEN ABOVE CHANGES ARE ONLY TO FEE ADDRESS AND/OR PRACTITIONERS OF RECORD, FILE LETTER IN THE FILE JACKET.

PTO-FMD
TALBOT-1/97

United States Patent [19] [11] **4,215,294**

Taggart [45] **Jul. 29, 1980**

[54] **AUTOMATIC INTENSITY CONTROL CIRCUIT FOR AN OSCILLOSCOPE**

[75] Inventor: **John E. Taggart,** Beaverton, Oreg.

[73] Assignee: **Tektronix, Inc.,** Beaverton, Oreg.

[21] Appl. No.: **954,065**

[22] Filed: **Oct. 23, 1978**

[51] **Int. Cl.**[2] **H01J 29/52**

[52] **U.S. Cl.** **315/383;** 358/168

[58] **Field of Search** 315/383, 30, 381; 358/168

[56] **References Cited**

U.S. PATENT DOCUMENTS

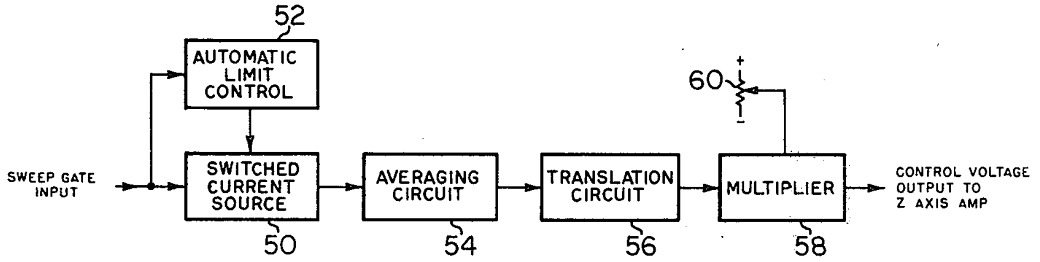
3,757,156	9/1973	Müeller et al.	315/30
3,775,637	11/1973	Brady	315/30
3,848,945	11/1974	Holzrichter	315/30

Primary Examiner—Theodore M. Blum
Attorney, Agent, or Firm—George T. Noe

[57] **ABSTRACT**

An automatic intensity control circuit is provided for maintaining a constant perceived display brightness in an oscilloscope under varied operating conditions. The circuit includes an averaging circuit, a translation circuit, and a multiplier circuit to develop a cathode-ray tube grid bias control voltage which is inversely proportional to the duty cycle of the time-base sweep gate signal. Two or more such automatic intensity control circuits may be multiplexed for multi-trace oscilloscopes to maintain a constant perceived brightness when alternating between two or more traces.

8 Claims, 4 Drawing Figures



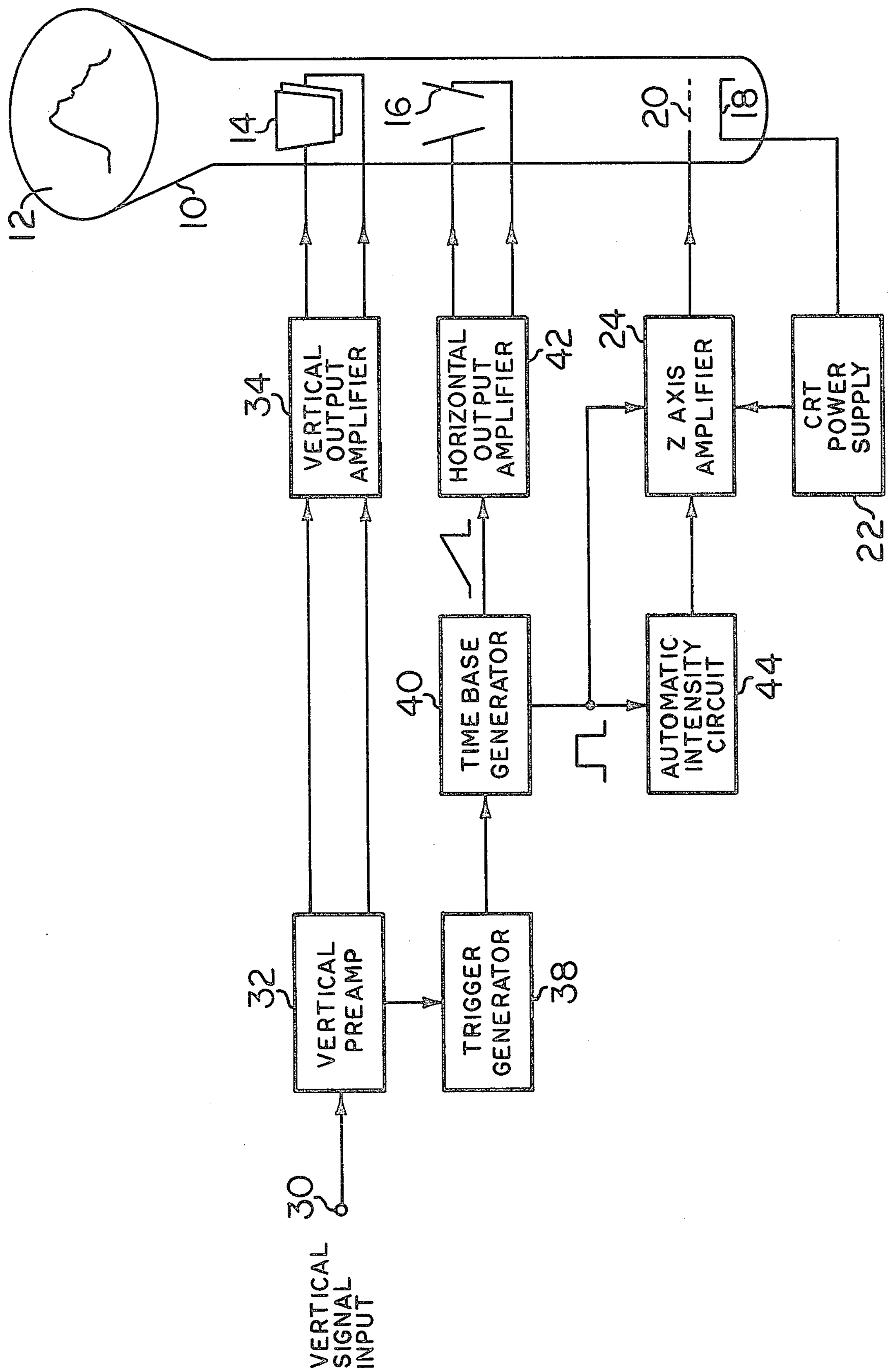

12
10
14
16
20
18
34
VERTICAL OUTPUT AMPLIFIER
HORIZONTAL OUTPUT AMPLIFIER
42
24
Z AXIS AMPLIFIER
CRT POWER SUPPLY
22
40
TIME BASE GENERATOR
AUTOMATIC INTENSITY CIRCUIT
44
32
VERTICAL PREAMP
TRIGGER GENERATOR
38
30
VERTICAL SIGNAL INPUT

FIG I

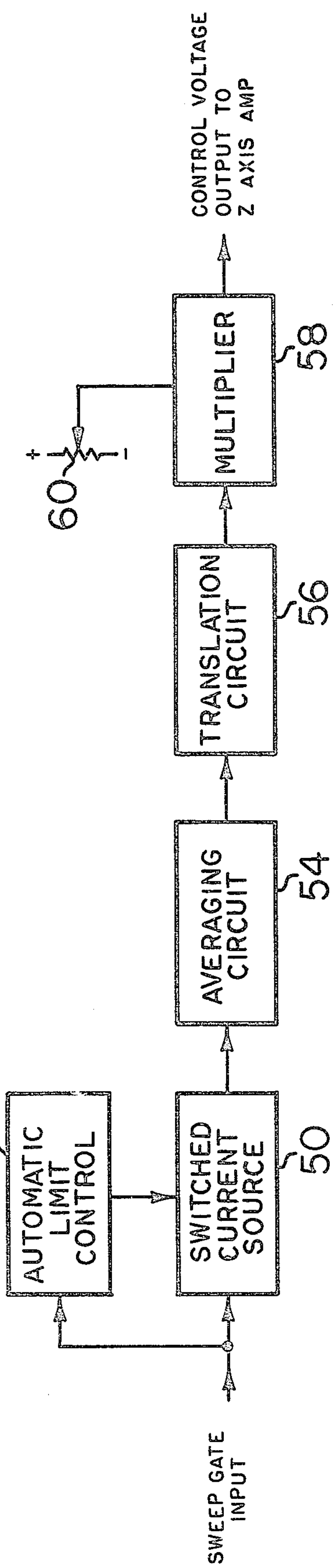

SWEEP GATE INPUT
AUTOMATIC LIMIT CONTROL
52
SWITCHED CURRENT SOURCE
50
AVERAGING CIRCUIT
54
TRANSLATION CIRCUIT
56
MULTIPLIER
58
60
CONTROL VOLTAGE OUTPUT TO Z AXIS AMP

FIG 2

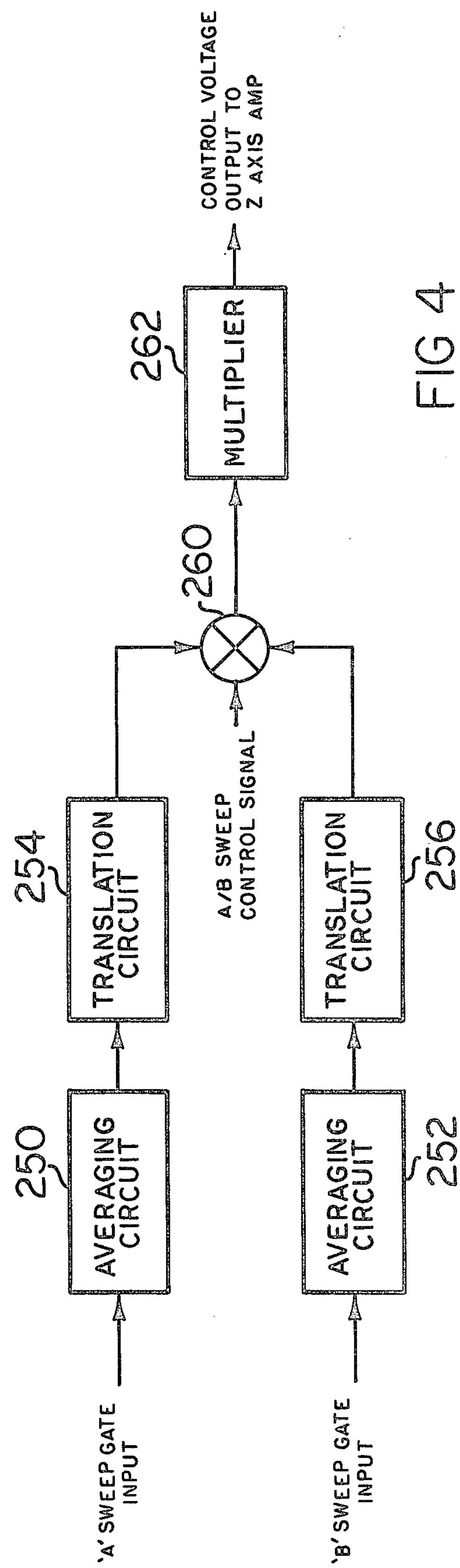

'A' SWEEP GATE INPUT
'B' SWEEP GATE INPUT
AVERAGING CIRCUIT
250
AVERAGING CIRCUIT
252
TRANSLATION CIRCUIT
254
TRANSLATION CIRCUIT
256
A/B SWEEP CONTROL SIGNAL
260
MULTIPLIER
262
CONTROL VOLTAGE OUTPUT TO Z AXIS AMP

FIG 4

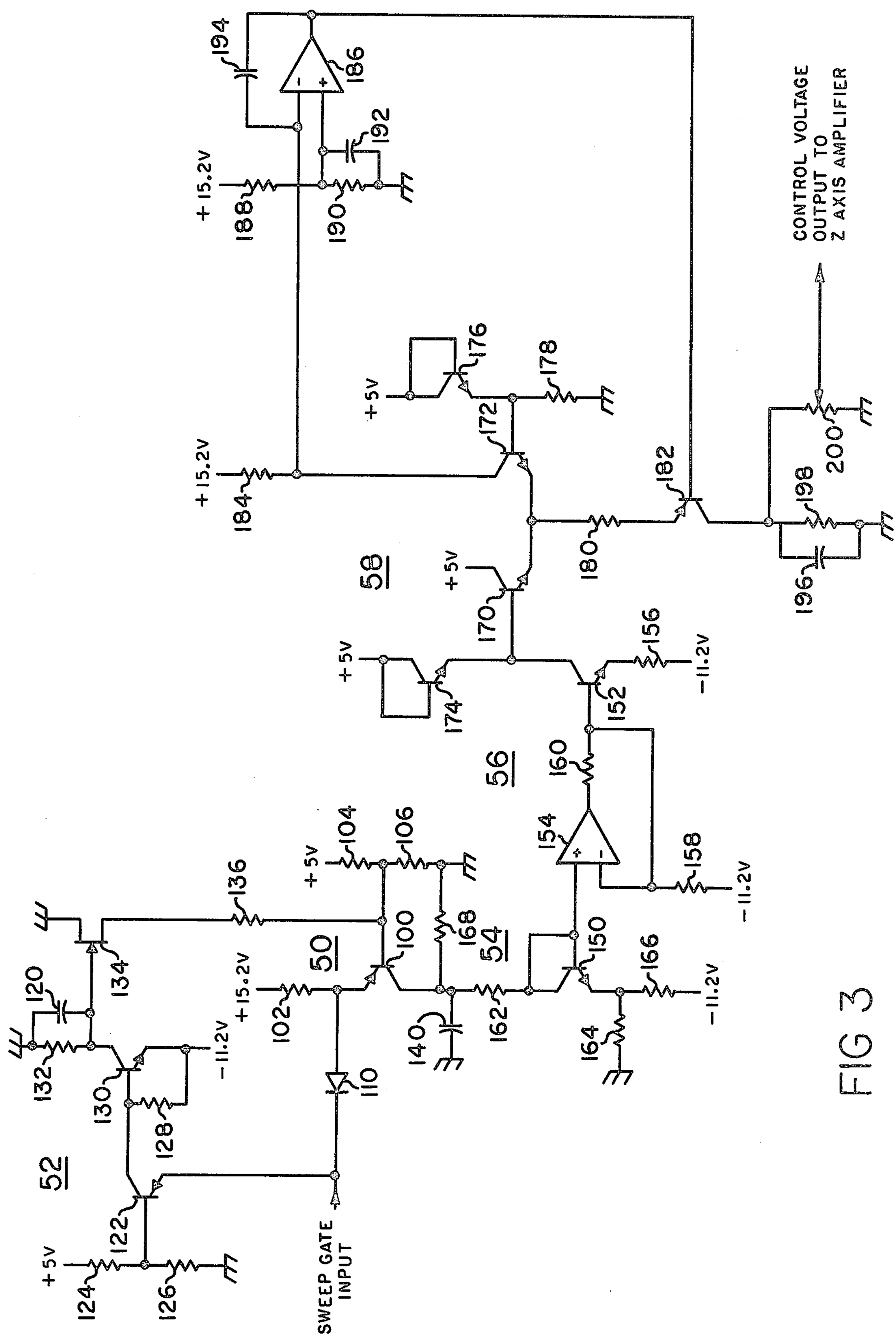

CONTROL VOLTAGE
OUTPUT TO
Z AXIS AMPLIFIER
SWEEP GATE
INPUT

FIG 3

AUTOMATIC INTENSITY CONTROL CIRCUIT FOR AN OSCILLOSCOPE

BACKGROUND OF THE INVENTION

The visual brightness, or intensity, of an oscilloscope display is dependent upon several factors, including cathode-ray tube beam current, phosphor writing rate, sweep rate, signal repetition rate, and the functional abilities of the eye of an observer. In particular, in repetitive-sweep operating situations wherein the sweep repeats at a rate higher than the critical fusion frequency of the eye, which is the frequency at which a flicker can no longer be discerned, light levels of the individual sweeps are integrated by the eye so that the average brightness perceived is proportional to the ratio of the time the sweep trace on the viewing screen to the time it is off the screen. Hence, the brightness of the display becomes dependent upon the timing of trigger signals which initiate the sweep and the setting of the sweep rate switch. Generally speaking, application of a lower repetition-rate signal to the oscilloscope vertical input causes a lower duty cycle and therefore requires a manual adjustment of the beam intensity to increase the display brightness, and application of a higher repetition-rate signal causes a higher duty cycle and therefore requires a manual adjustment of the beam intensity to reduce the display brightness.

Attempts to solve the foregoing problem have been inadequate. Typically, the prior art involves an averaging circuit which responds to a sweep sawtooth or gate signal to generate a control signal, which signal is then applied to the biasing circuit of the cathode-ray tube to change the electron beam current when changes occur in the duty factor of the sweep signal. However, the control signal voltage, which is added to a fixed unblanking voltage level, does not provide a first order correction of beam intensity. For example, it can be seen that if the control voltage is very small compared to the unblanking voltage, halving the duty cycle does not result in the desired doubling of the beam current to maintain a constant intensity. Instead, the overall bias voltage change is very slight, resulting in an almost imperceptible correction of brightness.

Another problem associated with averaging circuits of the prior art automatic intensity circuits is that when extremely low-repetition-rate signals are applied to the vertical amplifier input, long time periods exist between triggered sweeps. After the termination of a sweep, the averaging capacitor begins to discharge so that when a new sweep is initiated, little or no correction at all is available. Depending upon the sweep rate and the ability of the averaging circuit to respond, the result may be either a sweep trace which begins bright and then dims as the trace progresses, or a sweep trace which simply stays bright. Further, for oscilloscopes having dual time bases which are alternatively displayed, one trace may be normal intensity while the other may be bright.

SUMMARY OF THE INVENTION

The present invention relates generally to oscilloscope cathode-ray tube biasing circuits, and in particular to automatic intensity circuits for maintaining a constant perceived brightness under varied operating conditions, such as changes in the timing of triggering signals and changes in sweep rates.

The automatic intensity circuit includes an averaging circuit, a translation circuit, and a multiplier circuit.

The averaging circuit includes a current source which is switched on and off by the sweep gate signal, and a capacitor which is charged to a voltage which is proportional to the duty cycle of the sweep gate. Connected to the averaging circuit is the translation circuit, which is essentially a modified current mirror that performs a signal compression function and a characteristic-curve-fitting function to match the cathode-ray tube requirements. The multiplier circuit comprises a Gilbert multiplier with a feedback control loop and a current-to-voltage converter to provide a control voltage which is proportional to the reciprocal of the duty cycle of the sweep gate. The control voltage is output to the Z-axis amplifier to control the bias voltage applied to the cathode-ray tube grid. The overall effect is that changes in duty cycle of the sweep gate produce a reciprocal change in the beam intensity, maintaining a constant perceived brightness of the display.

A timing circuit may be provided to clamp the averaging circuit at a predetermined value if the pulse repetition frequency of the sweep gate falls below a predetermined limit, thereby providing a quick recovery of automatic intensity control upon initiation of a new sweep. Also, for dual time base oscilloscopes, two such automatic intensity control circuits may be provided, one for each of the two sweep traces. Appropriate multiplexing may be provided at either the input or the output of the multiplier circuit.

It is therefore one object of the present invention to provide an automatic intensity control circuit to maintain a constant perceived brightness of a cathode-ray tube display, irrespective of timing of trigger signals or sweep speed.

It is another object to provide an automatic intensity control circuit employing a multipler circuit so that correction provided thereby is proportional to the reciprocal of the error.

It is a further object to provide an automatic intensity control which limits trace brightness when the sweep repetition rate falls below a predetermined limit.

It is an additional object to provide an automatic intensity control which maintains a constant perceived trace brightness when alternating between two or more sweeps having different sweep speeds.

Other objects and advantages of the present invention will become apparent to those having ordinary skill in the art when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a block diagram of an oscilloscope having an automatic intensity control;

FIG. **2** shows a block diagram of an automatic intensity control circuit in accordance with the present invention;

FIG. **3** shows a detailed schematic of the automatic intensity control circuit of FIG. **2**; and

FIG. **4** shows a block diagram of a multiplexed dual automatic intensity control.

DETAILED DESCRIPTION

Referring to FIG. **1**, there is shown a block diagram of an oscilloscope. A cathode-ray tube (CRT) **10** is provided with a display screen **12**, a pair of vertical deflection plates **14**, a pair of horizontal deflection plates **16**, and an electron gun including a cathode **18** and a grid **20** for producing an electron beam. Other

CRT elements, such as focus electrodes and accelerating anodes, are not essential to an understanding of the present invention, and are therefore omitted. A CRT power supply **22** produces an appropriate high voltage, for example, −2000 volts, for operation of the CRT, and such high voltage is applied to the cathode **18** and to a biasing circuit portion of Z-axis amplifier **24** to control the grid-to-cathode voltage.

A signal to be displayed upon the display screen **12** of the CRT is applied via a vertical input terminal **30** to a vertical preamplifier **32**. The vertical preamplifier includes signal coupling and attenuator circuits to condition the input signal, which is then applied to the vertical output amplifier **34**. The vertical output amplifier provides a push-pull output signal having an amplitude suitable to drive the vertical deflection plates **14** to deflect the electron beam in a vertical direction in accordance with the instantaneous amplitude of the input signal. Assuming a repetitive input signal, a sample thereof is applied to a trigger generator circuit **38**, wherein the signal is compared with a predetermined reference voltage to produce sweep triggers, which are applied to a time-base generator circuit **40** to initiate a recurrent sweep-driving sawtooth signal. The time base generator **40** includes timing circuits to provide a range of selectable predetermined sweep rates. The sweep sawtooth signal is applied to a horizontal output amplifier **42**, where it is split into a push-pull signal suitable to drive the horizontal deflection plates **16** to deflect the electron beam in a horizontal direction in accordance with instantaneous amplitude of the sweep sawtooth signal. A gate signal is produced coincident with the sweep sawtooth signal by the time base generator **40**, which gate signal is simultaneously applied to the Z axis amplifier **24** and to an automatic intensity control circuit **44**. As mentioned previously, the Z axis amplifier **24** controls the CRT grid voltage, and, hence, beam intensity and display brightness. The sweep gate is utilized to blank the CRT during sweep retrace or flyback. The automatic intensity control circuit **44**, which is to be described in detail, develops a control voltage which is proportional to the reciprocal of the duty cycle of the sweep gate. This control voltage is applied to the Z-axis amplifier to control the CRT bias voltage to maintain a constant perceived brightness of the display.

A block diagram of the automatic intensity control circuit **44** is shown in FIG. **2**. The sweep gate signal may be applied simultaneously to a switched current source **50** and an automatic limit control circuit **52** which will be discussed later. The current source **50** is switched on by the sweep gate during the time that the sweep is running, that is, while a sweep sawtooth is being produced, and a predetermined constant current is passed to an averaging circuit **54**. When the sweep is off, the current source is off. Thus the averaging circuit **54** responds to a gated current to develop an output which is proportional to the duty cycle of the sweep gate.

The averaging circuit output is applied to a translation circuit **56**, which is essentially a modified current mirror that performs a signal compression function and a characteristic-curve-fitting function to match the operating requirements of the CRT, since the grid bias versus beam current of the CRT is a non-linear function. The current ouput from the translation circuit **56** is applied to a multiplier circuit **58**. The multiplier circuit may suitably be a Gilbert multiplier employing a feedback loop and a current-to-voltage converter to provide a control voltage which is proportional to the reciprocal of the duty cycle of the sweep gate. A front-panel intensity or brightness control, represented by variable resistor **60**, may be incorporated into the multiplier circuit so that the control voltage output therefrom includes the manually adjustable control component as well as the automatic control component. The control voltage output is applied to the Z-axis amplifier to control the CRT grid voltage, as shown in FIG. **1**.

The automatic limit control circuit **52** mentioned hereinabove may be provided to clamp the averaging circuit at a predetermined value if the pulse repetition frequency of the sweep gate falls below a predetermined limit, thereby limiting the maximum display brightness and providing a quick recovery of automatic intensity control upon initiation of a new sweep. During the time that a sweep is running, the automatic limit control circuit **52** is reset and held. Upon termination of the sweep, the limit control circuit is activated and a predetermined time interval is started. At the end of this time interval, if no new sweep has been initiated, the limit control circuit **52** turns on the current source **50**, which in turn passes current to the averaging circuit **54**. The Z-axis amplifier sees this action as the equivalent of a unity duty cycle and sets the CRT to a predetermined viewing intensity as established by the front-panel intensity control. Upon initiation of a new sweep, the automatic light control circuit **52** is reset and the current source **50** is under control of the sweep gate signal applied thereto. Of course, as long as the sweep recurs above a predetermined rate, the automatic limit contro circuit will be successively reset on each sweep and thereby not complete the timing cycle described above.

FIG. **3** shows a detailed schematic of the automatic intensity control circuit just described in block diagram terms in connection with FIG. **2**. The switched current source **50** includes a transistor **100**, the emitter of which is connected through a current-setting resistor **102** to a suitable source of positive voltage. The base of transistor **100** is connected to the junction of bias-setting resistors **104** and **106**, which are connected between a suitable positive voltage supply and ground to form a voltage divider. A diode **110** is connected in the circuit path between the gate signal input and the emitter of transistor **100** to control the switching of the current source. The sweep gate signal may be described in terms of logical highs and lows, and may indeed be effected by logic circuitry within the time-base generator. When the sweep is running, the sweep gate is high, and diode **110** is reverse biased. This allows transistor **100** to conduct. During the time that the sweep is off, the gate signal is low, forward-biasing diode **110** and pulling the emitter of transistor **100** negative, turning the transistor off.

The automatic limit control circuit **52** is connected between the sweep gate signal input and the base of transistor **100**, and comprises principally capacitor **120**, its charge and discharge paths, and control circuitry therefor. The emitter of a transistor **122** is connected to the sweep gate input path, while the base thereof is connected to the junction of a pair of biasing resistors **124** and **126** connected as a voltage divider between a suitable positive voltage supply and ground. The collector of transistor **122** is connected through a collector-load resistor **128** to a suitable negative voltage supply. A transistor **130** has its base connected to the collector of transistor **122**, and its emitter connected to the aforementioned negative voltage supply. The previously

mentioned capacitor **120** is connected in parallel with a resistor **132**, and this combination is connected between the collector of transistor **130** and ground. Transistor **130** provides the charging path for capacitor **120**, and resistor **132** provides the discharge path. Finally, to complete the automatic limit control circuit, a field-effect transistor (FET) **134** and resistor **136** are serially connected between ground and the base of the current source transistor **100**, and the gate of FET **134** is connected to the junction of capacitor **120**, resistor **132**, and the collector of transistor **130**. When the sweep gate signal is high (sweep running), transistor **122** is turned on, turning resistor **130** on to provide substantial charging current to capacitor **120**. The collector voltage of transistor **130** moves negative as the capacitor quickly charges, pinching off the channel of FET **134** and thus preventing any current through resistor **136**. Of course, during this period, the current source transistor **100** is also turned on, as discussed in the preceding paragraph. Upon termination of the sweep, the sweep gate signal goes low, turning off transistors **122** and **130**, as well as current-source transistor **100**, and allowing capacitor **120** to begin to discharge through resistor **132** at an RC-controlled rate. After a predetermined interval of time following the termination of a sweep, capacitor **120** discharges to a voltage which biases FET **134** into conduction. When FET **134** turns on, the base of the current-source transistor **100** is pulled negative due to the voltage developed across the FET and resistor **136**, causing current to pass through transistor **100** to the averaging circuit **54**. Upon initiation of a new sweep, the sweep gate signal goes high, resetting the limit control circuit by turning on transistors **122** and **130**, causing capacitor **120** to charge and thereby turn off FET **134**. As described above in connection with the block diagram of FIG. **2**, as long as the sweep recurs above a predetermined rate, the automatic limit control circuit will successively reset on each sweep and thereby not complete the timing cycle to turn on the current source.

The averaging circuit **54** comprises principally capacitor **140** and its charge and discharge paths. Associated with the averaging circuit **54** is the current source **50**, which provides the charging path for capacitor **140**, and the translation circuit **56**, which provides the discharge path.

The translation circuit **56** is actually a modified current mirror comprising a diode-connected transistor **150** and a transistor **152**, with a unity-gain buffer amplified **154** interposed between the bases of these transistors. A resistor **156** is connected between the emitter of transistor **152** and the negative supply. Associated with the unity-gain buffer amplifier **154** are equal-valued resistors **158** and **160**. The collector and base of transistor **150** are connected through a resistor **162** to capacitor **140** and the collector of transistor **100**. The emitter of transistor **150** is connected to the junction of resistors **164** and **166**, which resistors form a voltage divider between ground and the negative voltage supply to slightly elevate the transistor emitter above the supply. A resistor **168**, which may suitably have a value of several megohms, is connected between ground and the junction of resistor **162**, capacitor **140**, and the collector of transistor **100** to mainatain at least some current through transistor **150** if for some reason transistor **100** or capacitor **140** fail to supply current through resistor **162**.

When the current source **50** is gated on by the positive-going sweep gate pulse, a constant current, which

may be about 2.5 milliamperes, for example, flows from the collector of transistor **100** into the averaging circuit **140**. Depending upon the state of charge of capacitor **140** and the duty cycle of the sweep gate, a current flows through resistor **162** and transistor **150** which is representative of the average voltage of the sweep gate signal and hence is proportional to the duty cycle of the sweep gate. The voltage developed at the collector and base of transistor **150** is transmitted via the high-impedance buffer amplifier **154** to the base of transistor **152**. While the operation of transistor **152** "mirrors" the conduction of transistor **150**, the transistor **152** collector current is scaled in accordance with the value of resistor **156**. Furthermore, the operating point of transistor **152** may be shifted slightly from the operating point of transistor **150** to effect a match of the automatic intensity circuit output voltage to the requirements of the CRT. For example, in a specific embodiment constructed and tested, the parallel combination of resistors **164** and **166** was about 67 ohms, the value of resistor **156** was about 1.40 kilohms, the current through transistor **150** ranged from a minimum of one microampere to 2.5 milliamperes, and the current through transistor **152** ranged from a minimum of 20 microamperes to a maximum of 100 microamperes. Therefore, in summarizing the operation of the translation circuit **56**, the volt-ampere characteristic of the diode-connected transistor **150** in series with the parallel combination of resistors **164** and **166** is utilized to effect a CRT characteristic curve-fitting function, the emitter resistance of transistor **150** effects a shift along that curve to establish the operating point of transistor **152** within a dynamic range mandated by the CRT, and transistor **152** provides a compressed output version of the average circuit current.

The multiplier circuit **58** receives the current output from the translation circuit **56** and develops a control voltage therefrom which is functionally related to the reciprocal of the duty cycle of the sweep gate signal. Emitter-coupled transistors **170** and **172** together with the linearizing diode-connected transistors **174** and **176** connected to the bases thereof from a basic Gilbert multiplier circuit. Input current is applied via transistors **152** and **174**. A fixed current is applied to transistor **176** via a resistor **178**. Emitter current for transistors **170** and **172** is supplied by a resistor **180** connected thereto, the other end of resistor **180** being connected to the emitter of a control transistor **182**. The collectors of transistors **170**, **174**, and **176** are connected directly to a suitable positive low voltage supply, while the collector of transistor **172** is connected through a collector-load resistor **184** to a suitable positive voltage supply. A control loop including an operational amplifier **186** is connected between the collector of transistor **172** and the base of transistor **182**. A reference voltage established by a voltage divider comprising resistors **188** and **190** is applied to the positive input terminal of operational amplifier **186**, while the multiplier output at the collector of transistor **172** is applied to the negative input terminal. A capacitor **192** is connected across resistor **190** to stabilize the positive input against power supply variations, and a capacitor **194** is connected between the negative input terminal and the operational amplifier output to prevent oscillation. The collector of transistor **182** is connected to ground through the parallel combination of capacitor **196** and resistors **198** and **200**. The output control voltage is developed across this parallel combination, and since this network is effectively included in the emitter circuit of the multiplier, a

division function is actually performed, and, consequently, the control voltage is functionally related to the reciprocal of the sweep gate duty cycle. The effect is that when the sweep gate duty cycle is halved, e.g., reduced from 0.1 to 0.05, the output control voltage is effectively doubled. Conversely, doubling the sweep gate duty cycle causes the control voltage to be halved. Resistor **200** may suitably be the front-panel inensity or brightness control.

The overall circuit works as follows. Suppose that the triggering rate from incoming signals is reduced, causing a reduction in the number of sweeps per unit time to be integrated by the eye. This would result in an apparent dimming of the display. However, the reduction in the sweep gate duty cycle causes a reduction of output current from the averaging circuit. This action in turn results in a reduction of input current to the multiplier circuit from the translation circuit, increasing the base voltage of transistor **170**, shifting current away from transistor **172**. The corresponding rise in transistor **172** collector voltage is inverted by operational amplifier **186** and applied to the base of transistor **182**. Transistor **182** increases its conduction, developing a positive-going rise in the control voltage developed across the output resistors **198** and **200**. The increased control voltage is applied via the Z-axis amplifier to the CRT grid, increasing the beam intensity and consequently increasing the brightness of the perceived display.

The principles described hereinabove may be extended to dual-sweep oscilloscopes. FIG. **4** shows a block diagram of a multiplexed dual automatic intensity control system, wherein the two sweep generators are identified as the A sweep and the B sweep. The A and B sweep gate signals are applied to a pair of separate averaging circuits **250** and **252** respectively. These averaging circuits include gated current sources and thus are identical to those described earlier. The outputs from the averaging circuits are applied to a pair of translation circuits **254** and **256** respectively, which also operate as described earlier. The outputs from the translation circuits are applied to a switching circuit **260**, which may be switched by a control signal which also switches or multiplexes the A and B sweep channels. Such switching circuits are well known in the art, and may suitably be a flipflop or a multivibrator which controls the conduction states of FET's or bipolar transistors through which the translation circuit output currents are to be passed. The single output from the switching circuit **260** is applied to a single multiplier circuit **262** to produce a control voltage to be applied to the CRT grid via the Z-axis amplifier to thereby control beam intensity of whichever sweep is being displayed. Alternatively, two multiplier circuits could be employed in an arrangement where the control voltage outputs therefrom are multiplexed.

While I have shown and described herein the preferred embodiment of my invention, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from my invention in its broader aspects.

What I claim as being novel is:

1. An automatic intensity control circuit for an oscilloscope, comprising:

means for receiving at least one periodic signal and producing an electrical average value which is proportional to the duty cycle of said periodic signal;

means responsive to said average value for producing a control signal which is proportional to the reciprocal of said duty cycle of said periodic signal; and

means for coupling said control signal to a cathode ray tube to control the beam current thereof.

2. An automatic intensity control circuit in accordance with claim **1** wherein said means for producing said electrical average value includes a current source coupled to capacitor, said current source being switched on and off by said periodic signal.

3. An automatic intensity control circuit in accordance with claim **2** further including automatic limit control means for turning on said current source after a predetermined time interval.

4. An automatic intensity control circuit in accordance with claim **3** wherein said automatic limit control means comprises a resettable timing circuit and electronic switch means coupled to said current source.

5. An automatic intensity control circuit in accordance with claim **1** wherein said means for producing a control signal includes a multiplier circuit.

6. An automatic intensity control circuit in accordance with claim **5** wherein said multiplier circuit comprises an emitter-coupled pair of transistors, a pair of linearizing diodes coupled to the respective bases of said transistors, a current-to-voltage converter circuit coupled to the emitters of said transistors, and a feedback loop coupled between one collector of said emitter-coupled pair of transistors and said current-to-voltage converter circuit.

7. An automatic intensity control circuit in accordance with claim **1** wherein said means for producing a control signal further includes a translation circuit including a nonlinear conduction device and a signal compression device for matching said control signal to operating characteristics of said cathode ray tube.

8. An automatic intensity control circuit in accordance with claim **1** further including means for receiving at least one additional periodic signal and producing an additional electrical average value which is proportional to the duty cycle of said additional periodic signal,

and multiplexing means for providing a single control signal output.

* * * * *

United States Patent [19]

Chan et al.

[11] **4,334,244**

[45] **Jun. 8, 1982**

[54] **ADAPTIVE IMAGE ENHANCEMENT SYSTEM**

[75] Inventors: **James K. Chan,** Cerritos; **Curtis L. May,** San Pedro; **Allan Spooner,** Cypress, all of Calif.

[73] Assignee: **Magnavox Government and Industrial Electronics Company,** Fort Wayne, Ind.

[21] Appl. No.: **173,005**

[22] Filed: **Jul. 28, 1980**

[51] **Int. Cl.**³ **H04N 5/14**

[52] **U.S. Cl.** **358/166;** 358/138

[58] **Field of Search** 358/36, 37, 162, 166, 358/167, 282, 284, 263, 138; 328/151

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,462,547 8/1969 Macovski 358/133

3,621,129 11/1971 Fisher 358/166

4,121,248 10/1978 Coale, Jr. 358/160

Primary Examiner—Joseph A. Orsino, Jr.

Attorney, Agent, or Firm—Christie, Parker & Hale

[57] **ABSTRACT**

An image enhancement system in which a running average of a group of digitized samples of a video signal and a median of a group of digitized samples are processed to form a gradient sample. The gradient sample is scaled in response to the noise level of the video signal. The gradient samples, average samples, and medium samples are combined by a processor which generates a corresponding sequence of output samples that are converted into an enhanced video signal from which an image is produced. The processor provides image edge enhancement for high gradients while providing increased noise filtering for low gradients.

9 Claims, 9 Drawing Figures

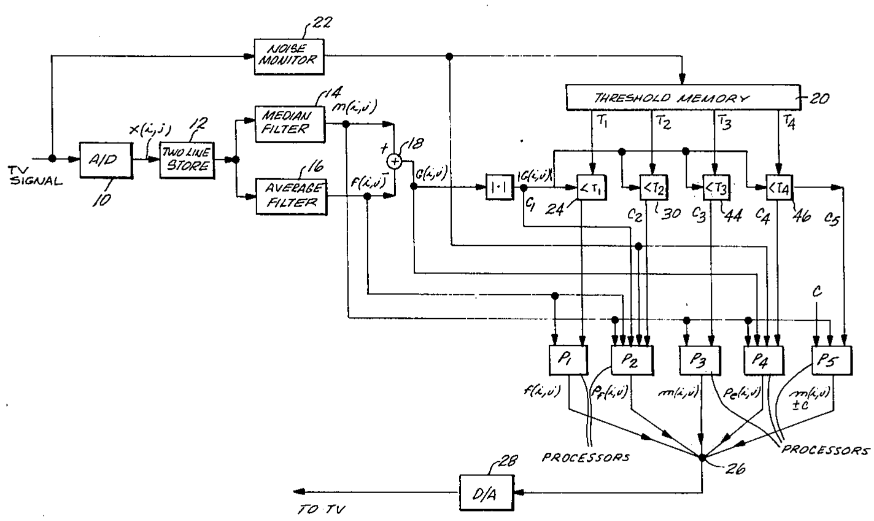


Fig. 1

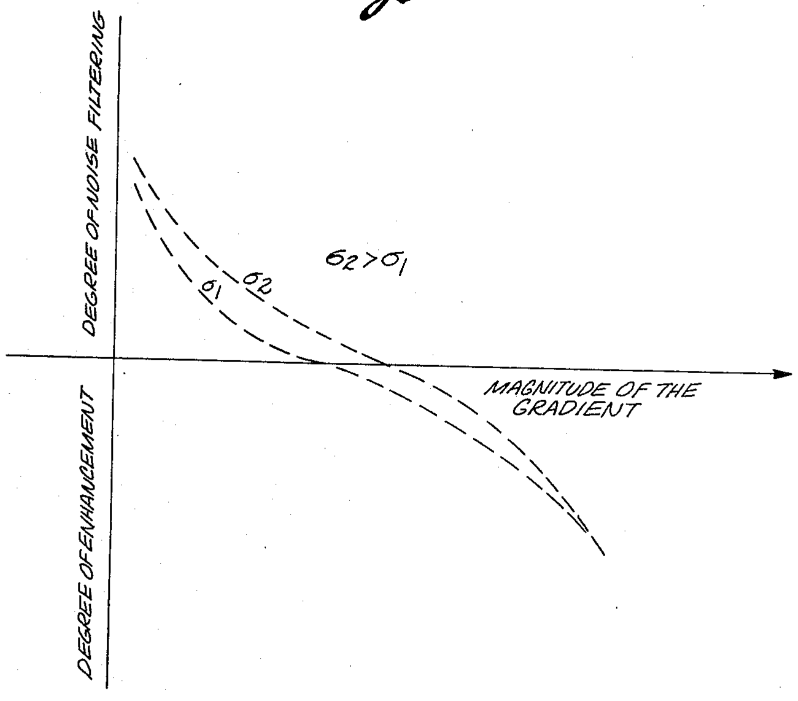
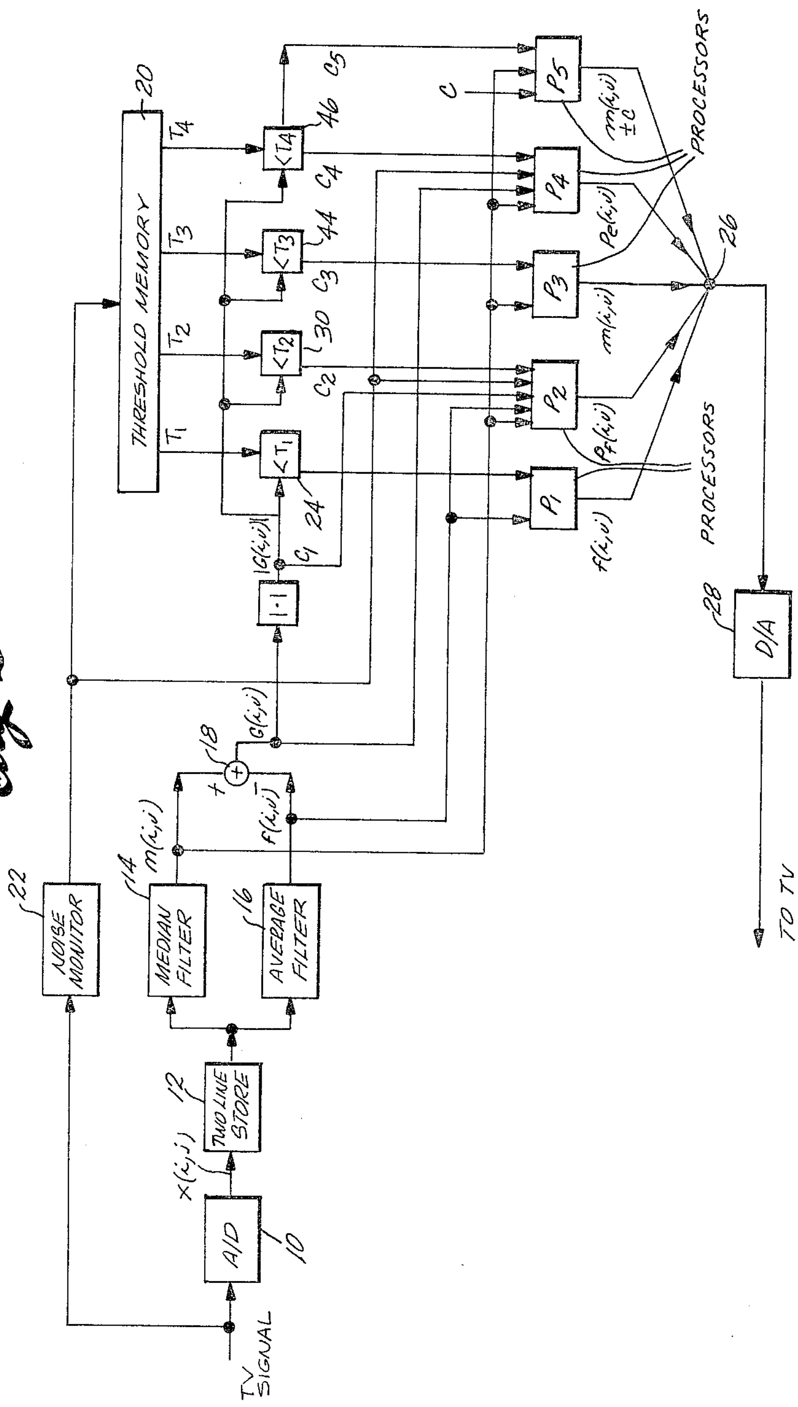
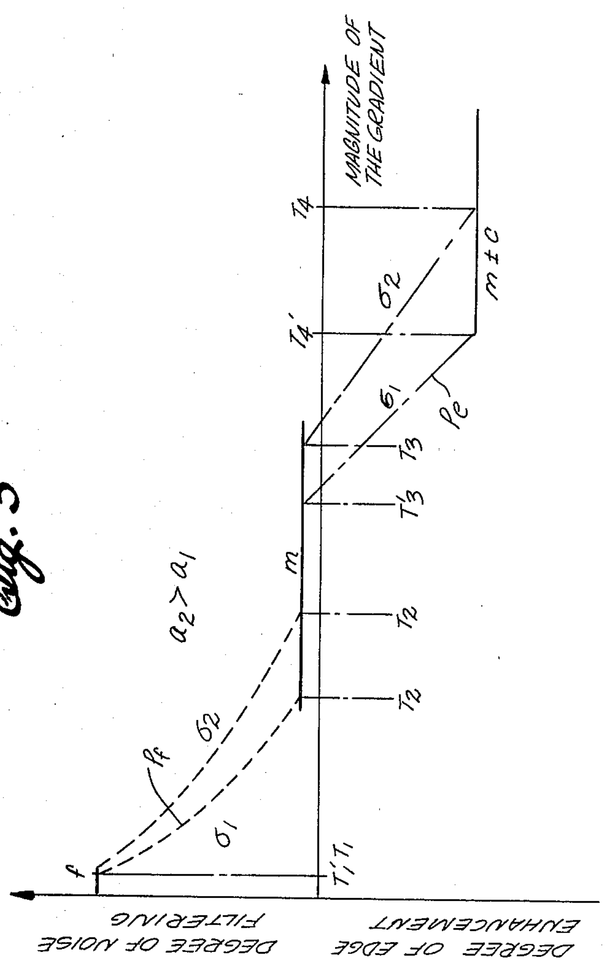

DEGREE OF NOISE FILTERING
DEGREE OF ENHANCEMENT
MAGNITUDE OF THE GRADIENT
σ2>σ1
σ1
σ2

Fig. 2



TV SIGNAL
A/D
10
x(i,j)
TWO LINE STORE
12
MEDIAN FILTER
14
AVERAGE FILTER
16
NOISE MONITOR
22
THRESHOLD MEMORY
20
T1
T2
T3
T4
18
m(i,j)
f(i,j)
G(i,j)
|·|
|G(i,j)|
<T1
<T2
<T3
<T4
24
30
44
46
C1
C2
C3
C4
C5
C
P1
P2
P3
P4
P5
f(i,j)
Pf(i,j)
m(i,j)
Pe(i,j)
m(i,j) ±C
PROCESSORS
PROCESSORS
26
D/A
28
TO TV

Fig. 3


MAGNITUDE OF THE GRADIENT
DEGREE OF NOISE FILTERING
DEGREE OF EDGE ENHANCEMENT
$a_2 > a_1$
m
m ± c

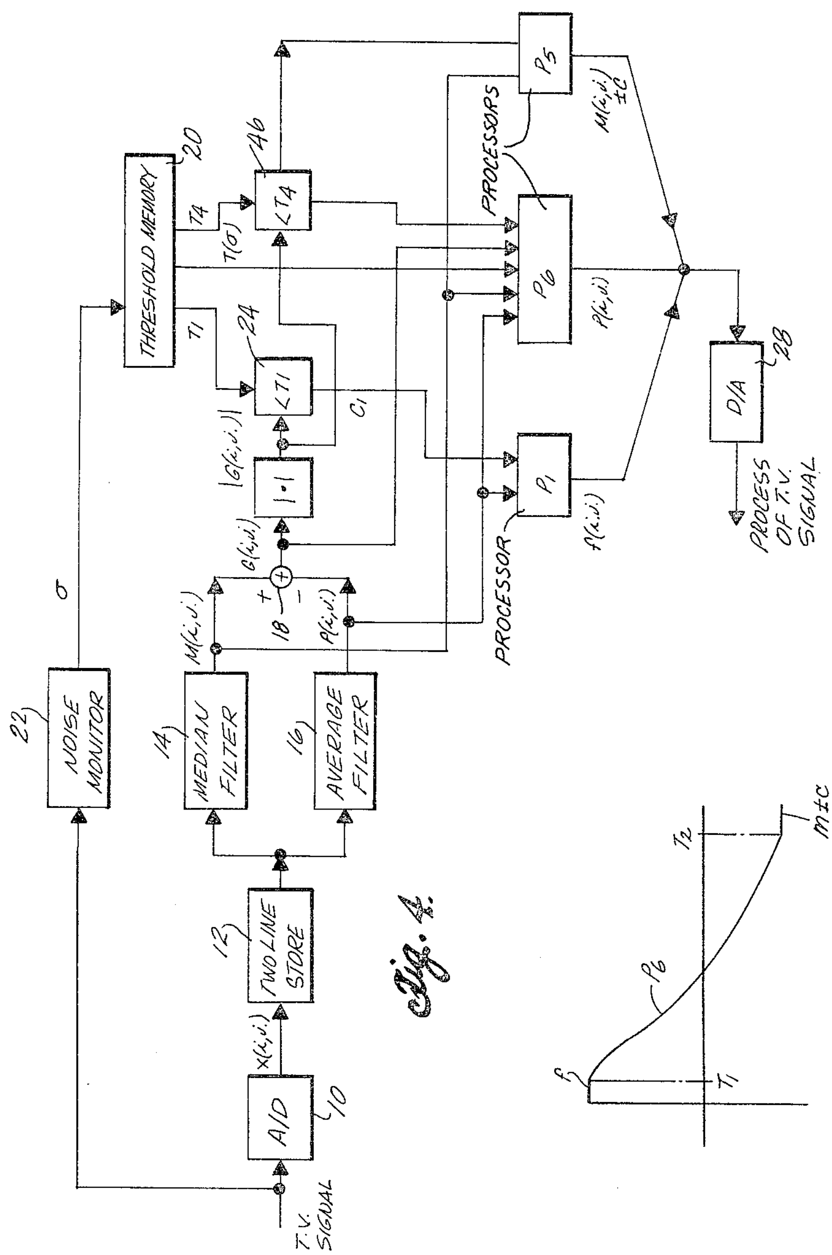
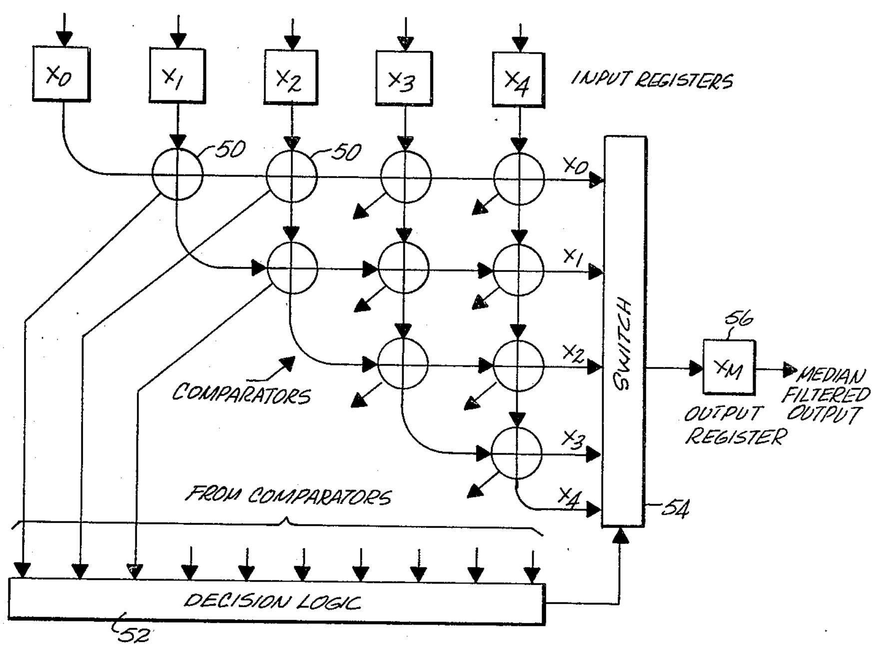

T.V. SIGNAL
A/D
10
x(i,j)
TWO LINE STORE
12
MEDIAN FILTER
14
AVERAGE FILTER
16
NOISE MONITOR
22
σ
THRESHOLD MEMORY
20
T1
T4
T(σ)
M(i,j)
P(i,j)
18
G(i,j)
|G(i,j)|
|·|
LT1
24
LT4
46
C1
P1
P6
P5
PROCESSOR
PROCESSORS
f(i,j)
P(i,j)
M(i,j) ±C
D/A
28
PROCESS OF T.V. SIGNAL

Fig. 4

f
P6
T1
T2
M±C

Fig. 5

Fig. 6



x0
x1
x2
x3
x4
INPUT REGISTERS
50
50
COMPARATORS
SWITCH
56
xM
MEDIAN FILTERED OUTPUT
OUTPUT REGISTER
54
FROM COMPARATORS
DECISION LOGIC
52

Fig. 7

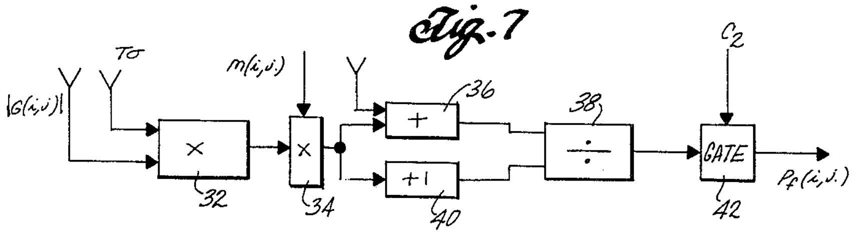


Fig. 8

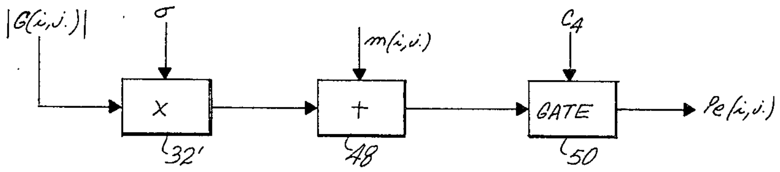
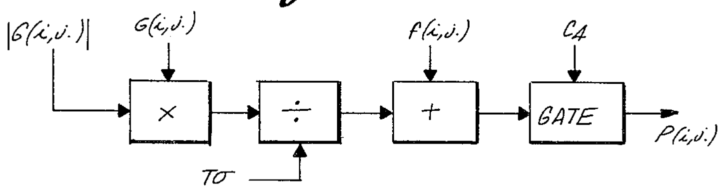


Fig. 9



ADAPTIVE IMAGE ENHANCEMENT SYSTEM

FIELD OF THE INVENTION

This invention relates to real-time image processing systems, and more particularly, to a video signal processing system for enhancing a video image by combined noise filtering and edge sharpening.

BACKGROUND OF THE INVENTION

Altering the image signal to present the viewer additional information or insight into factors concerning the pre-enhanced image are known. For example, two useful image enhancement operations are noise reduction and edge sharpening. Various filtering techniques for reducing noise have been proposed. For example, in U.S. Pat. No. 3,009,016—Graham there is described a noise reduction system in which a running average of picture samples (pixels) is compared with each new sample of the video signal, and if the picture sample does not exceed a predetermined theshold, the average of the samples is substituted. In copending application Ser. No. 133,606 filed Mar. 24, 1980, entitled "Adaptive Enhancement of Signal-to-Noise Ratio in Television Imagery," assigned to the same assignee as the present application, there is described a refined noise reduction system which generates an average from samples over an area extending both vertically above, and horizontally back from the current sample of the video signal. While both of these arrangements improve picture quality by reducing noise in areas of the picture which have relatively low detail and uniform intensity, they provide no enhancement by sharpening the edge between regions of contrasting intensity. Noise filtering and image sharpening involve conflicting requirements since filtering to reduce noise can blur the image while circuits for enhancing image sharpness will also enhance the noise.

SUMMARY OF THE INVENTION

The present invention is directed to a video image enhancement system which adapts itself to noise filtering of the video signal in image regions of nearly uniform intensity while providing edge sharpening in a region of sharp contrast and high detail. The system adapts globally to the input signal-to-noise (SNR) ratio so that if if the noise level is very low, there is enhancement by edge sharpening of all detail, but if the noise level is high, noise filtering but no edge enhancement is provided. This global adaption to the signal-to-noise ratio is independent of picture detail. In addition, the system adapts locally to the gradient magnitude to provide either noise filtering or edge enhancement with a smooth transition between these two conditions.

The video enhancement system of the present invention is based on the concepts that human observers detect the presence of noise much easier in a nearly uniform region than near an edge, while responding more to an edge brightness difference than to the same brightness difference in regions not adjacent to each other. This suggests that by dividing the images into regions of nearly uniform brightness and regions of higher contrast, it is possible to limit noise filtering to the low contrast regions and edge sharpening to the higher contrast regions. Because such segmentation requires some kind of thresholding to define the two regions, resulting in loss in spatial resolution and introduction of artifacts, the present invention provides a system which is adaptive to image content as measured

by the magnitude of the picture gradient. The degree of noise filtering is decreased gradually while the degree of edge sharpening is increased gradually as the magnitude of the gradient increases. At the same time, the rate of transition is made adaptive to the input signal-to-noise ratio of the image so that more adaptive noise filtering is performed if the image is noisier and more adaptive edge enhancement is performed if the image is cleaner.

This is accomplished by providing apparatus in which a succession of digitized samples of the video signal are generated and stored. With each new sample, a group of samples are averaged to generate an average sample while another group of samples are compared to generate the median sample of the group. Processing means generate a gradient sample corresponding to the absolute difference between the median and average samples. The gradient sample is scaled according to the noise level of the video signal independently of picture content. The scaled sample gradient is multiplied by the difference between the median and average samples and added to the average sample to generate an output sample. Successive output samples are converted to an output video signal for processing into an image.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention reference should be made to the accompanying drawings, wherein:

FIG. **1** is a graphical representation of the idealized characteristics of the enhancement system;

FIG. **2** is a schematic block diagram of one embodiment of the invention;

FIG. **3** is a graphical representation of the characteristics of the system of FIG. **2**;

FIG. **4** is a schematic block diagram of a preferred embodiment of the present invention;

FIG. **5** is a graphical representation of the characteristics of the embodiment of FIG. **4**;

FIG. **6** is a schematic block diagram of a median filter;

FIG. **7** is a block diagram of the processor P_2 of FIG. **2**;

FIG. **8** is a block diagram of the processor P_4 of FIG. **2**;

FIG. **9** is a block diagram of the processor P_6 of FIG. **4**.

DETAILED DESCRIPTION

Referring to FIG. **1**, there is shown the overall characteristics of a video adaptive image enhancement system having the required properties. As the picture gradient increases, the degree of average filtering to reduce noise is decreased and the degree of edge filtering increases. A family of curves for different levels of SNR, as indicated by σ, show the characteristic shifts to provide more or less average filtering while providing less or greater edge filtering as the noise level increases or decreases. It will be noted that the degree of noise filtering decreases gradually while the degree of edge sharpening increases gradually as the magnitude of the gradient increases. There is a smooth transition from the performance of the adaptive noise filter to the performance of the adaptive enhancer as the image content changes at different regions of the image. As shown by the family of curves, the rate of transition is made adaptive to the input signal-to-noise ratio of the image. Thus

the curve σ_1 represents an image generated from a video signal of relatively low SNR while the curve σ_2 corresponds to a video signal of higher SNR. Thus a system having the characteristics of FIG. **1** adapts locally to the image content as measured by the gradient magnitude and globally to the input SNR of the image.

Referring to FIG. **2**, there is shown a simplified block diagram of a video enhancement circuit according to the present invention which approximates the characteristics shown in FIG. **1**. The performance characteristics of the circuit of FIG. **2** are shown in FIG. **3**. A television video signal is applied to the input of the enhancement circuit. An analog-to-digital converter **10** quantizes the signal into a plurality of successive digitized samples or pixels. The signal amplitude represented by each pixel is defined as x(i,j), where i is the number of the row or line during one complete frame of the video image and j is the number of successive samples in one line. At least two complete rows are temporarily stored in a two-line store **12**, which may be a shift register. As each new sample is transferred into the register **12**, a sample from at least two rows above in the image is shifted out of the register.

For each sample x(i,j), a median sample m(i,j) is generated by a median filter **14**. The median filter looks at a group of samples in the store **12** and selects the sample point of the group which has the middle magnitude. Preferably the median filter **14** looks at five image points or pixels arranged in a cross pattern, that is, three successive points in the same row or line, and three vertical points with the center point being common to both the horizontal and vertical lines. A suitable circuit for the median filter **14** is described below in detail in connection with FIG. **6**.

At the same time and operating in parallel with the median filter is an average filter **16** which generates an output sample that is the average of a group or block of the samples stored in the store **12**. Various averaging patterns can be used, such as a running line average, an area average, or a more complex averaging arrangement, such as described in the above-identified patent application. The samples stored may correspond to a 3×3 pattern of image pixels. To simplify division in obtaining the average value, only eight samples are used instead of nine. This allows a division by eight, which in a binary system only requires a three digit left shift operation. The resulting output sample from the average filter **16** is designated f(i,j).

The magnitude of the gradient at any point on the picture can be determined by the difference in the median sample value m(i,j) and the average f(i,j). The magnitude of the gradient at any point on the image is given by $G(i,j)=m(i,j)-f(i,j)$. Thus the sample gradient is obtained by a subtracting circuit **18** which subtracts the digitized output from the average filter **16** from the digitized output of the median filter **14**.

The gradient magnitude provided by the output of the subtracter is used to activate one of five processing units P_1, P_2, P_3, P_4 or P_5 by comparing the gradient magnitude with a set of threshold values T_1, T_2, T_3 and T_4 derived from a table of threshold values stored in a threshold memory **20**. Any one of a plurality of sets of four threshold values are selected, depending on the signal-to-noise ratio (SNR) of the video signal as determined by a noise monitor circuit **22**. The noise monitor circuit **22**, as hereinafter described in detail, generates a digitized value which is proportional to the SNR of the video input signal. In its preferred form, the noise monitor circuit utilizes the equalizing pulses of a received television signal as a reference, since the waveshape of the pulses are standardized. Any noise in the received signal can be detected as distortion of the equalizing pulse waveform. Such a noise monitoring system is described, for example, in U.S. Pat. No. 4,044,381. The output of the noise monitor circuit **22** is used to address the memory **20** to select a corresponding set of four threshold values from the table of thresholds stored in the memory **20**.

The absolute value $|G(i,j)|$ of the gradient magnitude is compared with the first threshold value T_1 by a comparator circuit **24**. If the comparator indicates that the gradient value $|G(i,j)|$ is less than the first threshold value T_1, it activates the processor P_1. The processor P_1 is a simple gate circuit which is activated by the output C_1 from the comparator circuit **24** to gate the average sample from the average filter **16** to a common terminal **26** connected to the input of a digital-to-analog converter **28**. Thus the average value sample f(i,j) is substituted for the input sample x(i,j) in generating an enhanced TV video signal.

The absolute value $|G(i,j)|$ of the gradient is also compared by a comparator **30** with a threshold value T_2 which is larger than the value T_1. If the gradient value is equal to or greater than the threshold value T_2, the output of the comparator C_2 activates the processor P_2. The processor P_2, in response to the output m(i,j) of the median filter **14**, the output f(i,j) of the average filter **16**, the absolute value $|G(i,j)|$ of the gradient and the noise level as indicated by the output of the noise monitor **22**, generates an output sample $P_f(i,j)$ according to the following relation:

$$P_f(i,j) = \frac{f(i,j) + \alpha(\sigma)\,|G(i,j)|\,m(i,j)}{1 + \alpha(\sigma)\,|G(i,j)|}\,;\ |G(i,j)| < T(\sigma)$$

$\alpha(\sigma)$ is a noise factor which is a function of the SNR value σ. $T(\sigma)$ is the threshold value T_2 which is also a function of the SNR value σ.

The processor P_2 for carrying out the function of the equation 1 is shown in FIG. **7**. The absolute value $|G(i,j)|$ of the gradient is scaled by the noise factor $\alpha(\sigma)$ by a multiplier **32**. The output is then multiplied by the median value m(i,j) by a multiplier **34**. The output of the multiplier **34** is added to the average sample value f(i,j) by an adder **36** and applied to one input of a divider circuit **38**. The output of the multiplier **32** is increased by one by an "add-one" circuit **40** and used as the divisor for the divider circuit **38**. The output of the divider circuit **38** corresponds to the value $P_f(i,j)$ and is gated to the common terminal **26** by a gate **42** in response to the control signal C_2 from the comparator **30** when the gradient magnitude is greater than T_1 but less than T_2.

If the absolute value $|G(i,j)|$ of the gradient is greater than the threshold T_2 but less than the threshold T_3, a comparator **44** turns on a control signal C_3, activating the processor P_3. The processor P_3 is merely a gate for gating the median value m(i,j) to the common terminal **26**.

If the absolute value $|G(i,j)|$ of the gradient is greater than the threshold value T_3 but less than a threshold value T_4, a comparator **46** turns on a control signal C_4 which in turn activates the processor P_4 having the following characteristic:

$$P_e(i,j)=m(i,j)+\beta(\sigma)G(i,j);\ |G(i,j)|>T(\sigma)$$

The processor P_3 is shown in FIG. **8**. The processor P_4 again multiplies the absolute value $|G(i,j)|$ of the gradient with the noise factor $\beta(\sigma)$ by a multiplier **47**. The output of the multiplier **47** is added to the median value m(i,j) by an adder **48** to produce the desired edge enhanced value $P_e(i,j)$. This modified sample value is gated to the common terminal **26** through a gate **50** in response to the control signal C_4.

Finally, if the absolute value $|G(i,j)|$ of the gradient is greater than T_4, a maximum limit is set to prevent any excessive enhancement. The processor P_5 modifies the median value $m_{i,j}$ by adding or subtracting a constant value C and applying the output to the common terminal **26** in response to a control signal C_5 from the comparator **46**.

The characteristics of the circuit of FIG. **2** are shown in FIG. **3**. It will be seen that the characteristic of FIG. **3** is a close approximation to the desired characteristic of FIG. **1**. From FIG. **3** it will be seen that if the magnitude of the gradient is below T_1, the output sample corresponding to the average value f(i,j). Between T_1 and T_2, the adaptive noise filter sample value P_f is used, which reduces the degree of noise filtering as the magnitude of the gradient increases. Once the magnitude of the gradient exceeds the threshold T_2, the output sample of the median filter is used as the output sample, resulting in less noise filtering but improved edge detail. With the magnitude of the gradient between the range of T_3 and T_4, the edge enhanced sample P_e, which varies with the change in the magnitude of the gradient, is used as the output sample. Finally, a maximum degree of edge enhancement is provided by using the m(i,j)$\pm$C as the sample output. FIG. **3** shows two different sets of thresholds, T and T', corresponding to two different levels of noise, σ_1 and σ_2.

A preferred embodiment is shown in FIG. **4** in which a single processor P_6 provides a modified sample value that provides both noise filtering and edge enhancement of the resulting image. The circuit is otherwise the same as the arrangement in FIG. **2** except that the threshold memory provides only two threshold values, T_1 and T_4. Processor P_6 is activated between the full gradient range from T_1 to T_4. The processor P_6 provides a combined noise filtering and edge enhancement according to the following relation:

$$P(i,j) = f(i,j) + \frac{|G(i,j)|}{T(\sigma)} G(i,j)$$

For a fixed SNR, the absolute value $|G(i,j)|$ of the gradient acts as a non-linear adaptive gain factor which changes P(i,j) from $P_f(i,j)$ to $P_e(i,j)$ smoothly as the gradient increases. Since $T(\sigma)$ increases as σ increases, this gain factor is de-emphasized as the input picture gets noisier. FIG. **9** shows a block diagram of processor P_6.

The performance of the circuit depends largely on the size of the averaging and the median filters. For example, averaging a block of $n \times n$ pixels gives an improvement in SNR of 20 $\log_{10}$ (n). The larger that n is, the better is the noise filtering. With n=3, that is, averaging a 3×3 matrix of pixels, the noise filtering is improved by about 9.5 db. Performance of the median filter depends on both the size and the shape of the block of pixels used. Increasing the number increases the noise filtering but produces a greater loss of spatial

resolution. Five pixels arranged in a cross has been found to produce satisfactory results.

One embodiment of a median filter is shown in the block diagram of FIG. **6**. The five samples from the cross-shaped block, designated x_0, x_1, x_2, x_3 and x_4, are applied to a group of comparator circuits **50** from the store **12**. Ten comparison circuits are required to compare each of the five samples with each of the other samples. Each comparator provides a binary coded output in which 0 represents less than and 1 represents greater than or equal. The ten binary bits from the ten comparators are applied to a decision logic circuit **52** which determines which of the five input samples is in the middle of the five samples. The decision logic sets a switch to connect the median value of the input samples to an output register **56**. The concept of a median filter has been described in the literature. See, for example, "Nonlinear (Nonsuperposable) Methods for Smoothing Data" by J. W. Tukey, Comp. Rec., 1974 EASCON, p. 673.

The averaging filter, in its simplest form, sums a group of the stored points, preferably arranged in a block, and divides by the number of points to generate an average value. An alternative averaging circuit is described in copending application Ser. No. 133,606 filed Mar. 24, 1980, entitled "Adaptive Enhancement of Signal-to-Noise Ratio in Television Imagery" by Curtis May and assigned to the same assignee as the present application.

From the above description it will be seen that a circuit is provided which provides both noise filtering and edge enhancement in the same image. The degree of noise filtering and edge enhancement adapts locally to image content and globally to the SNR of the image. As a result, degradation in spatial resolution or the introduction of artifacts such as "contouring" and "salt-and-pepper" effects are minimized. The averaging filter and the median filter can be tailored depending on application areas, giving the system considerable flexibility. Minimum storage is required and real-time operation for a TV system is no problem.

What is claimed is:

1. Apparatus for enhancing the image produced from a received video signal, comprising: means sampling the video signal at a predetermined rate to provide a succession of coded samples indicating the instantaneous amplitude of the video signal with each sampling, memory means storing a plurality of said coded samples, means inserting the coded samples into the memory means with each successive sampling of the video signal, means generating an average sample corresponding to the average of a predetermined group of samples stored in the memory means in response to each sampling of the video signal, means generating a median sample corresponding to the median of a predetermined group of samples stored in the memory means in response to each sampling of the video signal, subtraction means for generating a gradient sample with each sampling of the video signal corresponding to the median sample minus the average sample, processing means responsive to the average sample and the gradient sample for generating an output sample proportional to the sum of the average sample and the product of the gradient sample and the absolute value of the gradient sample, and means converting successive output samples to an output video signal.

2. Apparatus of claim **1** further including means responsive to the received video signal for generating a

noise signal indicative of the signal-to-noise ratio of the received video signal, and means scaling the product of the gradient sample and the absolute value of the gradient sample by an amount inversely related to the level of said noise signal.

3. Apparatus of claim 2 further including means generating a gradient threshold signal, means comparing the absolute value of the gradient sample with said threshold signal, the processing means including means for generating an output sample equal to the average sample when the absolute value of the gradient sample is less than said threshold signal.

4. Apparatus for enhancing the quality of an image produced from an input video signal, comprising:

analog-to-digital converter receiving the video signal and converting the signal to a succession of digital samples of the video signal, means storing a plurality of said digital samples, means selecting a first predetermined group of stored digital samples for generating a median sample corresponding in magnitude to the median value of said first group of stored digital samples in response to each new digital sample of the video signal, means selecting a second predetermined group of stored digital samples for generating an average sample corresponding in magnitude to the average value of said second group of stored samples in response to each new digital sample of the video signal, digital processing means for selecting one of a plurality of possible output samples in response to each average sample and each median sample, each of the possible output samples being dependent on the changes in the magnitude of the difference between the median sample and the average sample, and a digital-to-analog converter for converting the output samples of said digital processing means back to an output video signal.

5. Apparatus of claim 4 further including noise monitoring means responsive to the input video signal for generating a noise signal corresponding to and varying with the level of noise in the video signal, the processing means including means for scaling the output samples of said digital processing means in response to the noise signal.

6. Apparatus of claim 4 further including means for generating a threshold signal, and means comparing the threshold signal with the difference between the median signal and the average signal for gating the average sample directly to the digital-to-analog converter in place of the output sample from the processing means when said difference is below the level of said threshold signal.

7. Apparatus of claim 6 further including means responsive to the noise signal for varying the level of the threshold signal with changes in the noise level.

8. Apparatus of claim 4 wherein the processing means includes means multiplying said difference between the median sample and the average sample with the absolute value of said difference, and means adding the output of the multiplying means to the average sample to generate the output sample from the processing means.

9. Apparatus of claim 7 wherein the processing means includes means multiplying said difference between the median sample and the average sample with the absolute value of said difference, means scaling the output of the multiplying means in response to the noise signal, and means adding the output of the multiplying means to the average sample to generate the output sample.

* * * * *

United States Patent [19]
Okada

[11] **Patent Number:** **4,489,349**
[45] **Date of Patent:** **Dec. 18, 1984**

[54] **VIDEO BRIGHTNESS CONTROL CIRCUIT**

[75] Inventor: **Takashi Okada,** Yokohama, Japan

[73] Assignee: **Sony Corporation,** Tokyo, Japan

[21] Appl. No.: **230,394**

[22] Filed: **Feb. 2, 1981**

[30] **Foreign Application Priority Data**

Jan. 31, 1980 [JP] Japan 55-10667

[51] **Int. Cl.**[3] **H04N 5/68**
[52] **U.S. Cl.** **358/168;** 358/32; 358/164
[58] **Field of Search** 358/168, 39, 74, 243, 358/32, 164

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,255,691	9/1941	Wilson	358/164
3,619,496	11/1971	Lichtenstein	358/168
3,752,905	8/1973	Schneider	358/32
3,873,767	3/1975	Okada	358/168
3,980,822	9/1976	Suzuki	358/168
4,044,375	8/1977	Norman	358/168
4,091,419	5/1978	Rhee	358/168
4,298,885	11/1981	Okada	358/39

FOREIGN PATENT DOCUMENTS

2312150	1/1977	France	358/164
71604	1/1980	Japan	358/168

Primary Examiner—Tommy P. Chin
Attorney, Agent, or Firm—Lewis H. Eslinger; Alvin Sinderbrand

[57] **ABSTRACT**

A control circuit for controlling the relative brightness of a video signal includes an average picture level (APL) detector to measure the average brightness of the video signal and a brightness control circuit responsive to the detected average brightness to provide an output video signal wherein the picture areas containing most of the picture information are corrected to give greater contrast. In the output signal, portions corresponding to the black and peak white levels of the incoming video signals are provided substantially at the black and peak white levels, respectively, while the average brightness level of the output video signal is provided at an optimum level, such as 50%. The brightness control circuit can include a variable gamma correction circuit in which the value of gamma is automatically determined by a control signal provided from the APL detector.

21 Claims, 13 Drawing Figures

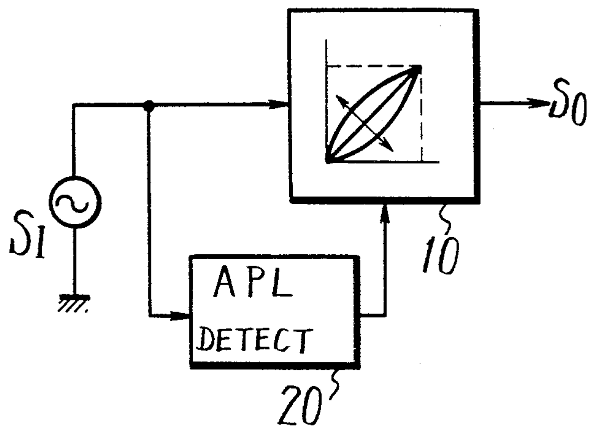


FIG. 1

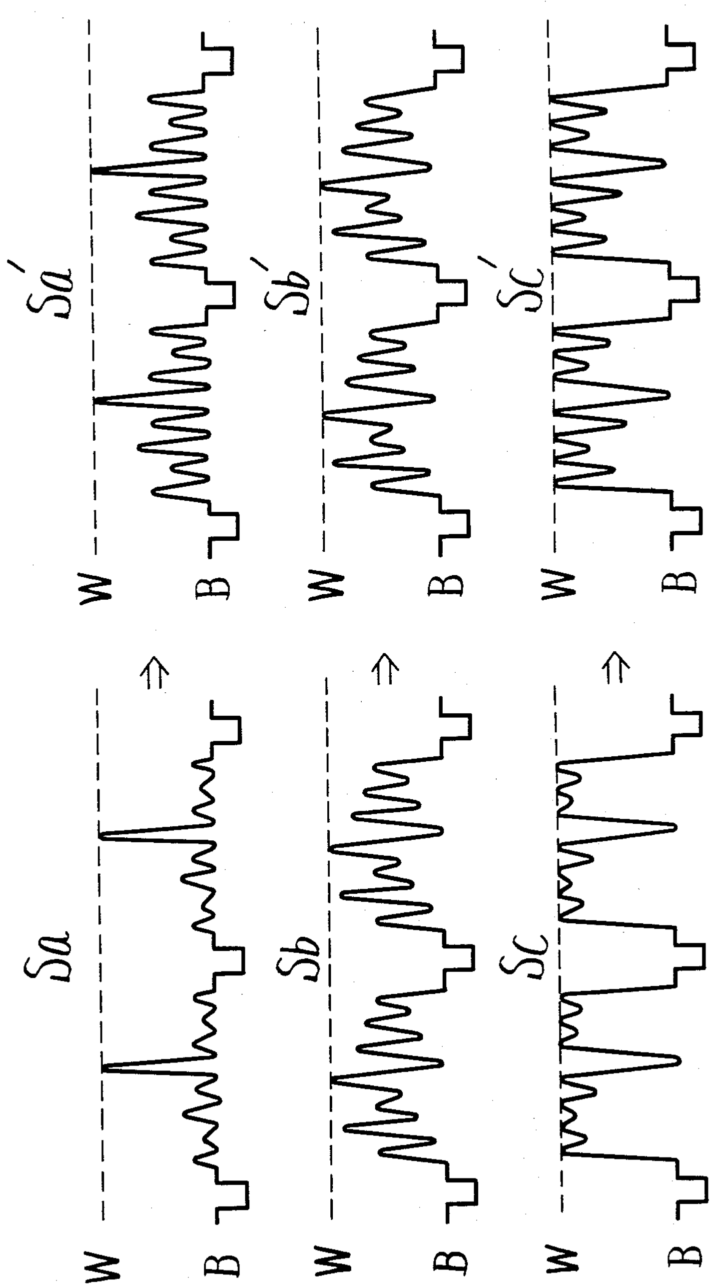


FIG. 2

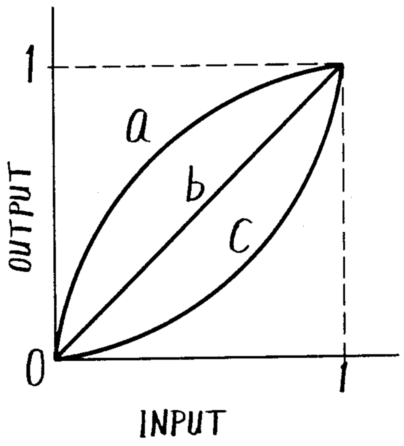


FIG. 3

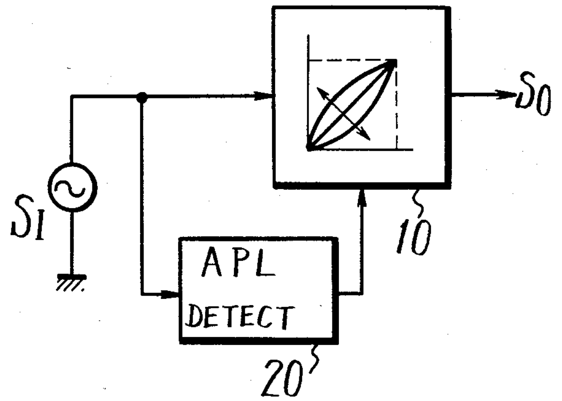


FIG. 4

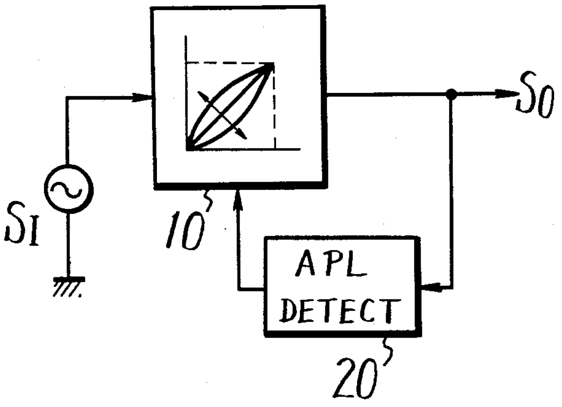


FIG. 5

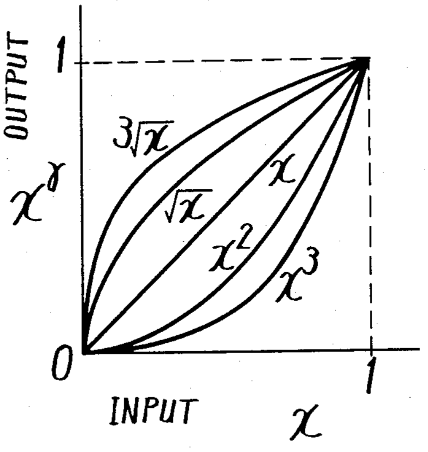
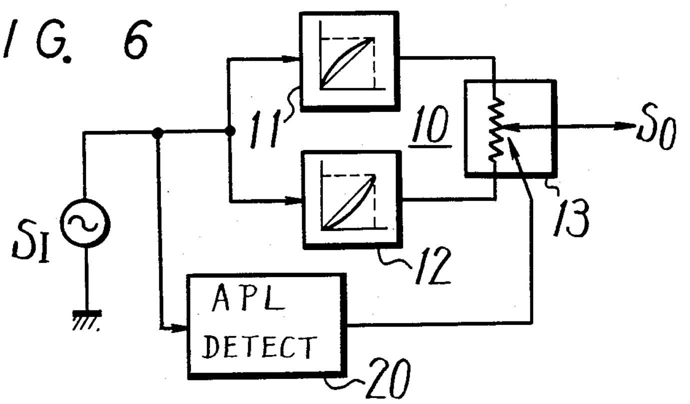
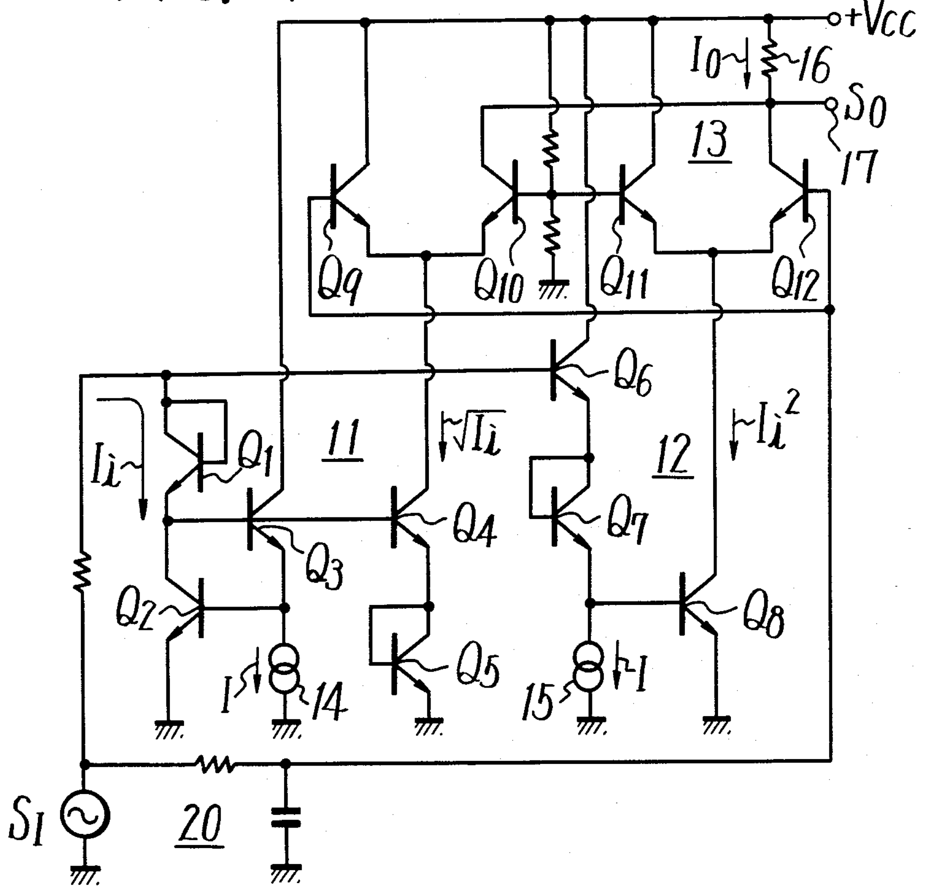


FIG. 6



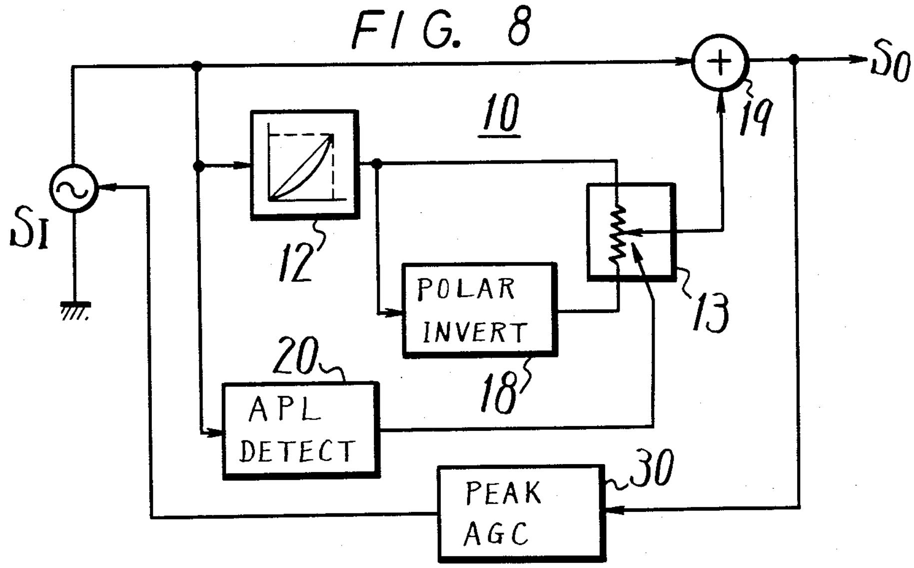
11
10
12
13
20
APL DETECT
S_I
S_0

FIG. 7



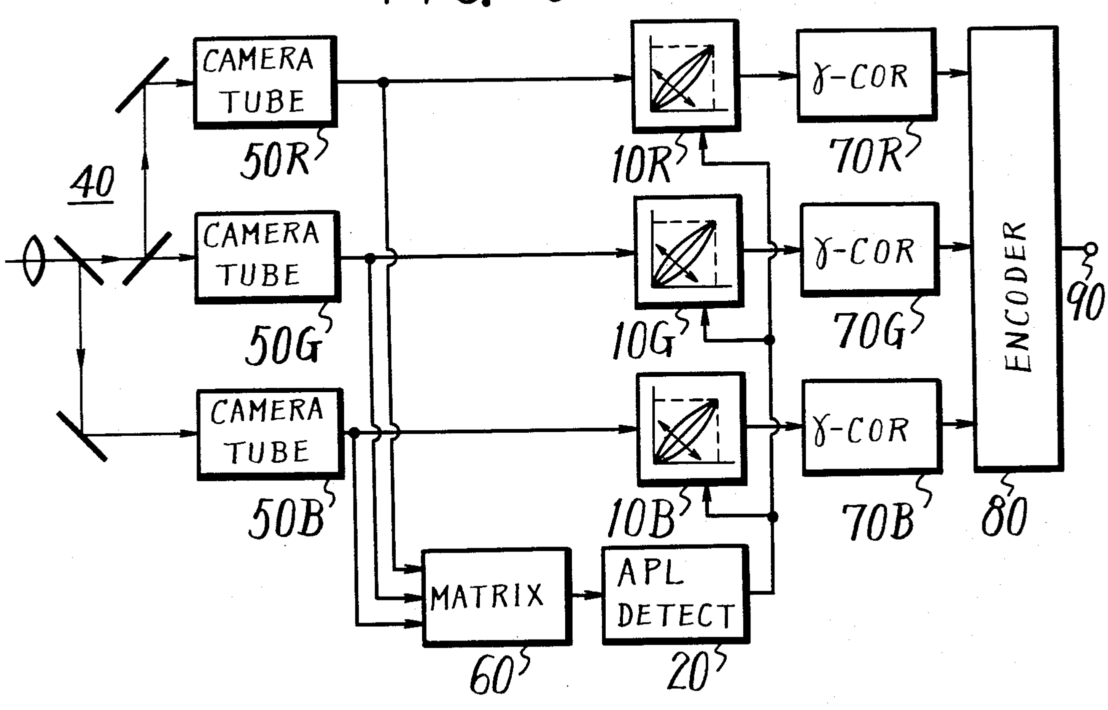
+Vcc
I_0
16
S_0
17
13
Q9
Q10
Q11
Q12
Q6
Q1
11
$\sqrt{I_i}$
12
I_i^2
I_i
Q4
Q7
Q3
Q2
Q8
Q5
I
14
15
I
S_I
20

FIG. 8



SO
10
19
SI
12
POLAR INVERT
13
20
APL DETECT
18
PEAK AGC
30

FIG. 9



CAMERA TUBE
50R
40
CAMERA TUBE
50G
CAMERA TUBE
50B
10R
10G
10B
γ-COR
70R
γ-COR
70G
γ-COR
70B
ENCODER
80
90
MATRIX
60
APL DETECT
20

FIG. 10

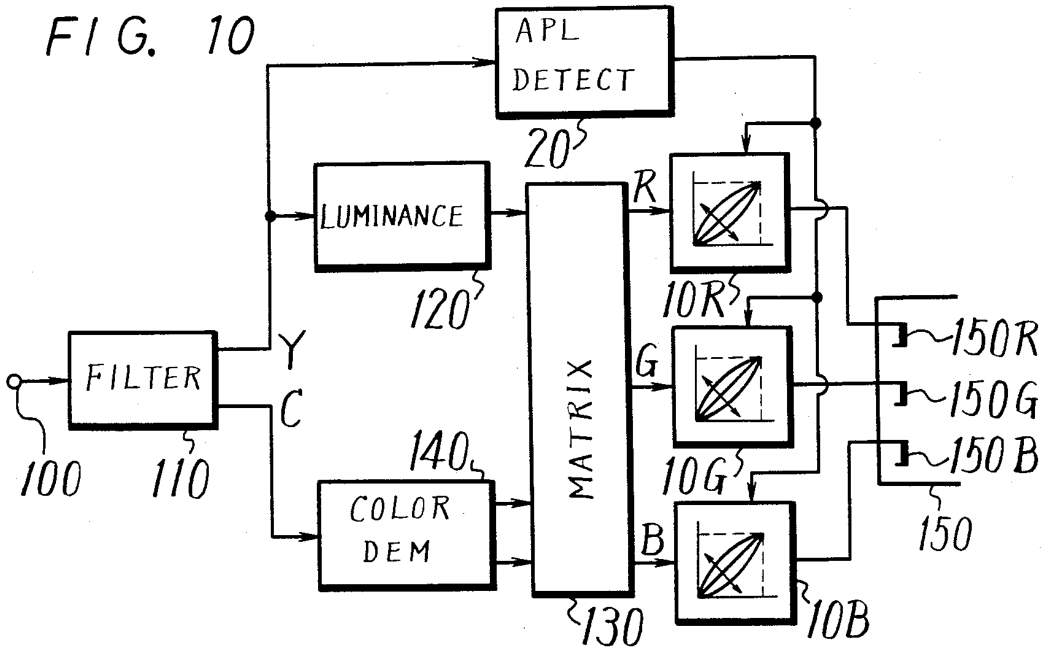


FIG. 11

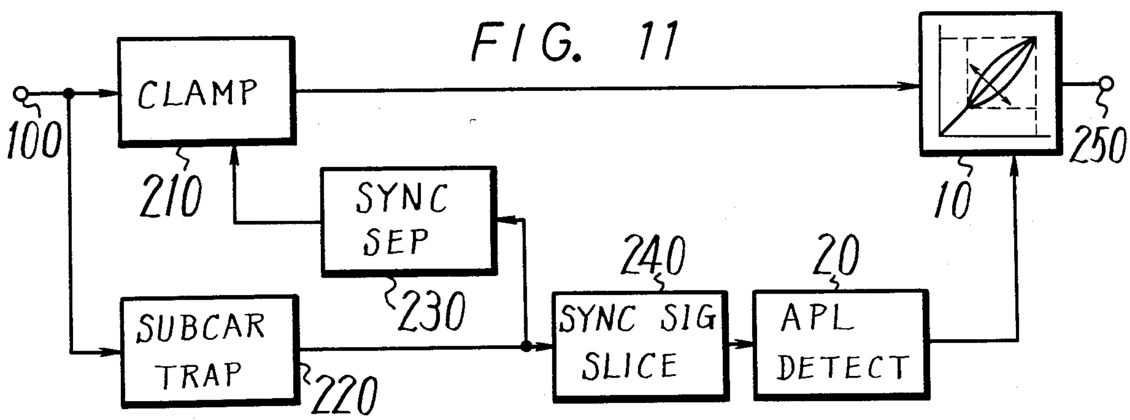
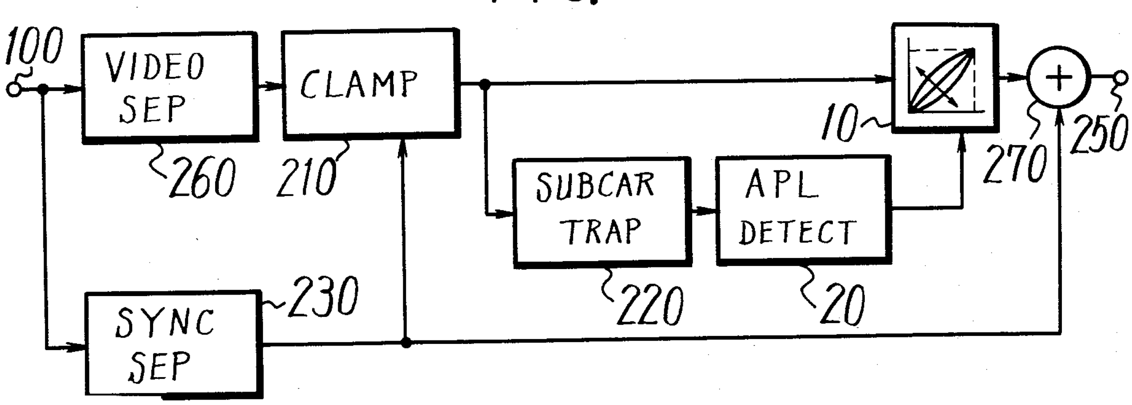


FIG. 12



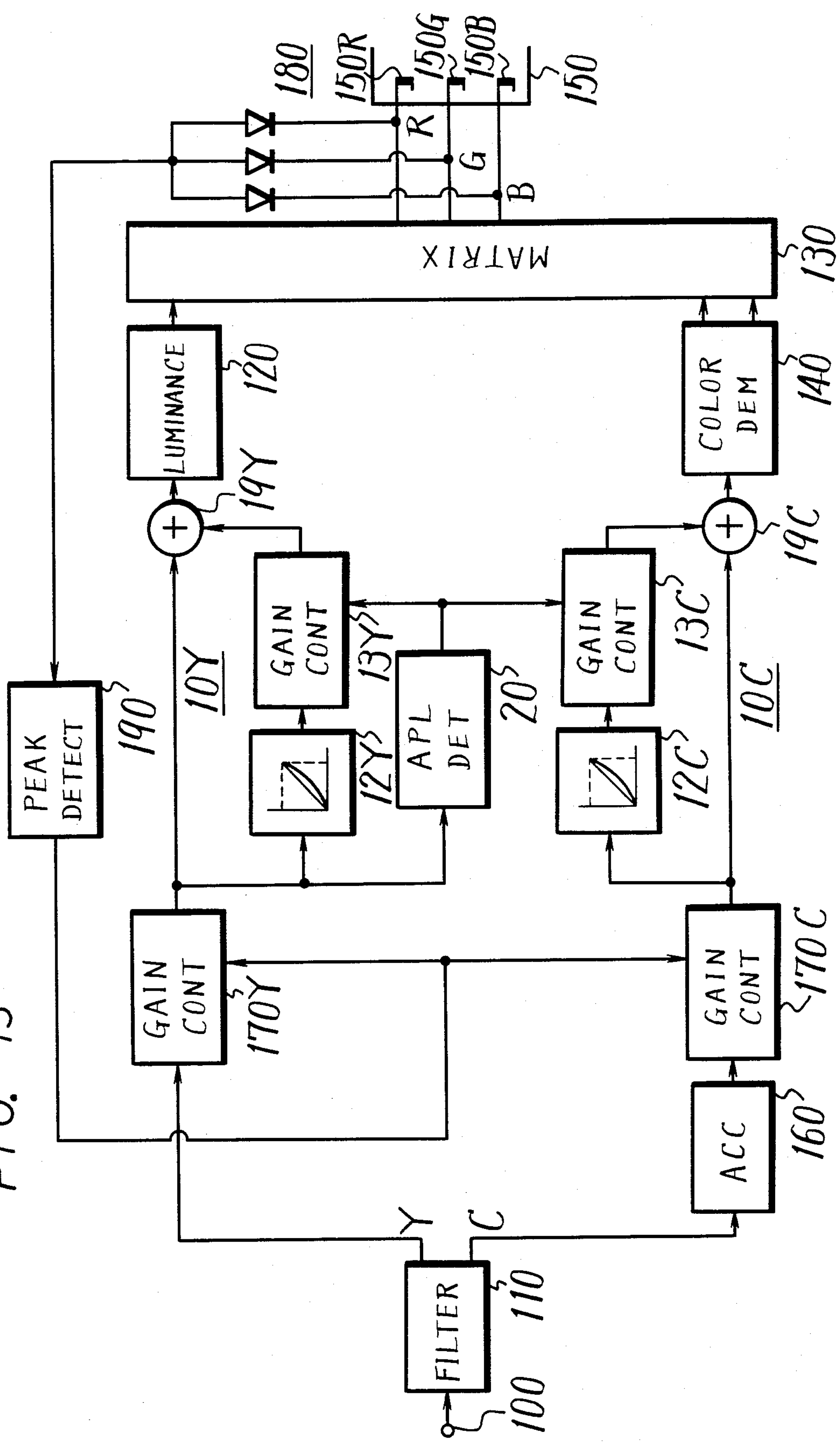

180
150R
150G
150B
150
R
G
B
MATRIX
130
LUMINANCE
120
COLOR DEM
140
19Y
19C
GAIN CONT
13Y
GAIN CONT
13C
APL DET
20
10Y
10C
12Y
12C
PEAK DETECT
190
GAIN CONT
170Y
GAIN CONT
170C
ACC
160
Y
C
FILTER
110
100

FIG. 13

VIDEO BRIGHTNESS CONTROL CIRCUIT

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to video signal processing circuitry and particularly relates to circuitry for controlling the brightness of a video signal so that detail of interest in a video picture will appear natural and have good contrast.

2. Brief Description of the Prior Art:

Natural illumination can have an extremely wide brightness range, and will necessarily have a vast range of contrast scales. The human eye adapts itself remarkably well for viewing naturally-lit objects and can with ease perceive detail in shadows and in brightly lit areas as well. Nevertheless, color video cameras and color video display apparatus are not easily adaptable to conditions of natural illumination, and current videocasting practices require special techniques, such as supplemental fill-in lighting, to provide a pleasing yet natural picture.

However, when such special techniques are unavailable, such as during on-scene news reporting, the picture presented on a display apparatus can be harsh and unpleasant. For example, if an on-the-spot newscast takes place at night with a newscaster at the news scene standing in front of a bright source, such as a flashing neon sign, the picture is likely to be harsh and without good detail. In such a scene, the presentation of the neon light is bright but the other objects in the picture are dark, and the contrast range among such objects is extremely narrow. Thus, except for the neon sign, the picture appears objectionably dim and observation of detail in the picture is difficult.

This problem can be understood by considering that while a color camera can be responsive to input light having an illumination range of from several hundred to several hundred thousand lux, the electrical output of the camera is limited to a range of, for example, 1 volt peak-to-peak. The input light must have a limited illumination range, e.g. 100 to 200 lux or several thousand to several tens of thousands of lux, in order that all of the video output signal remain within the range of 1 volt peak-to-peak. If these illumination limits are not observed, a conventional color television camera and display apparatus will not provide a good, pleasing picture.

Brightness adjustment in the video transmission is now carried out to a limited extent by use of so-called gamma (γ) correction. This process compensates for the differences in gamma values between the image pickup tube of a television camera and the cathode ray tube (CRT) of a television receiver.

Normally, the picked-up image is gamma-corrected before transmission so that the net gamma value of the image pickup and image display will be unity.

Conventionally, gamma correction is carried out on the image pickup side so that the output signal is skewed logarithmically at the saturated (white) side of the brightness range. Then, the skewed curve is expanded somewhat at the CRT, due to its inherent gamma characteristic, so that the picture brightness is correct.

Generally, if the overall gamma characteristic is logarithmic, the dark picture portions will have expanded contrast, and fine dark or shadow detail is reproduced. Conversely, if the gamma characteristic is exponential,

the bright portions will have expanded contrast, and detail in brightly lit areas will be clear.

Further, the lower illumination intensity portions of the video signal are affected by noise in the video apparatus. Consequently, a good video picture cannot be obtained for any scene unless the picture brightness is properly adjusted to span the entire dynamic range of the video apparatus. Accordingly, the actual brightness of an object in the scene does not convert exactly to a particular level of the video output signal, especially if the object is not evenly illuminated. The image of such an object in an unevenly-lit scene is not easily visible when reproduced on a video screen, and hence fatigues the eyes, making viewing somewhat tiring and unpleasant.

OBJECTS AND SUMMARY OF THE INVENTION

Accordingly, it is an object of this invention to provide a technique wherein an image on a video screen is provided with the portion of the picture of most interest having relatively high contrast.

It is a further object of this invention to provide a correction circuit for use, for example, in a color television receiver, which will automatically adjust the brightness of the television signal so that a pleasing picture is presented on the display screen of the receiver, even when the scene is unevenly illuminated.

According to an aspect of this invention, a control circuit for controlling the brightness of a video signal that fluctuates between a peak dark level, such as the black level, and a peak bright level, such as the peak white level, about an average brightness level comprises an average picture level (APL) detector for detecting the average brightness level and, in response, providing a corresponding control signal, and a brightness adjusting circuit for optimizing the brightness of the video signal in response to the control signal, and providing a video output signal in which respective portions of the video output signal corresponding to portions of the incoming video signal at the peak dark level and the peak bright level are provided at the peak dark level and the peak bright level, but in which the average picture level is provided at an optimum level, such as the 50% brightness level.

The brightness adjusting circuit can favorably be formed as an adjustable gamma circuit, in which the value of gamma is determined in accordance with the control signal from the APL detector. In other words, the brightness adjusting circuit has an input-output characteristic such that for a video input signal having a level proportional to a value X, where X is in the range $0 \leqq X \leqq 1$, the video output signal is provided at a level proportional to a value X^{γ}, and the value γ is automatically determined in response to the control signal so that the video output signal has an APL at the optimum level.

A correction circuit according to this invention can be incorporated into a color television camera, in which case three brightness adjusting circuits can be included to be operative on respective primary color signals. The circuit of this invention can also be incorporated in a color television receiver. In such case, three brightness adjusting circuits can be provided, each operative upon a separate primary color signal, a single brightness adjusting circuit, operative upon both the chrominance and luminance components of a composite color video signal can be provided, or, alternatively, two brightness

adjusting circuits can be provided, one operative upon the luminance component, the other operative upon the chrominance component of a composite color video signal.

Various other features and advantages of the present invention will be apparent from the following description of several preferred embodiments, when considered with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a set of charts showing video waveforms before and after treatment in the correction circuit of this invention.

FIG. **2** is an input-output graph for explaining the operation of a portion of the correction circuit of this invention.

FIGS. **3** and **4** are diagrammatic views showing the basic construction of the circuit of this invention.

FIG. **5** is an input-output graph for explaining the present invention.

FIG. **6** is a systematic block diagram showing one embodiment of the correction circuit of this invention.

FIG. **7** is a detailed circuit diagram showing a practical example of the embodiment of FIG. **6**.

FIG. **8** is a systematic block diagram showing another embodiment of the circuit of this invention.

FIG. **9** is a systematic block diagram of a three-tube color television camera incorporating the present invention therein.

FIG. **10** is a systematic block diagram of a portion of a video display apparatus incorporating the present invention.

FIGS. **11** and **12** are systematic block diagrams of video signal processing circuits for use in video receivers and incorporating the present invention.

FIG. **13** is a systematic block diagram of a portion of a video receiver incorporating the present invention.

DETAILED DESCRIPTIONN OF SEVERAL PREFERRED EMBODIMENTS

With reference to the drawings, and initially to FIG. **1**, typical video signals Sa, Sb, Sc will be considered. In the charts of FIG. **1**, the video signals have an amplitude ranging between a black level B and a peak white level W. Each of the video signals Sa, Sb, Sc, has a broad brightness amplitude range extending from black to white.

The signal Sa represents a dimly-lit scene having a single bright portion. In this case, most of the picture detail is in dark tones in the dimly lit portion, and only a small portion of the picture is bright. As a result, the signal-to-noise ratio of the picture is quite low and the signal Sa produces a dirty or hazy picture.

In the signal Sb, bright and dark tones are substantially uniformly distributed, indicating that the televised scene is ideally illuminated. The entire dynamic range of the signal Sb is used effectively so that the signal Sb has a high signal-to-noise ratio, and will produce a fine quality picture.

The signal Sc represents a scene which is brightly lit, but which includes a dark object. Here most of the detail is in bright tones, and the brightness of the picture will cause such detail to become very faint. Signals such as the signal Sc occur rather often when televising scenes out of doors, especially scenes including snow or scenes at a beach.

As aforesaid, the video signals Sa and Sc, although faithfully corresponding to the objects in the respective televised scenes, include detail in the dimly and brightly lit portions, respectively, which will not be easy to see, due to the limited signal-to-noise ratio of the video display apparatus. According to this invention, the video signals Sa and Sc have their brightness levels optimized so that important detail in the picture portions having the largest amount of picture information can be observed with good contrast. Consequently, the image displayed on the video screen will be pleasing and easy to view.

In order to achieve this, the video signal is processed through a circuit having an input-output characteristic as shown in FIG. **2**.

When the signal Sa is supplied an input, the input-output characteristic is caused to follow curve a of FIG. **2** so that the dimly-lit portions are expanded in contrast while the brightly-lit portions are compressed in contrast, with the result that the processed video signal Sa′ is provided as an output video signal.

When the signal Sc is applied as an input, the input-output characteristic thereof follows curve c, so that the brightly-lit portions of the video picture are expanded, while the dimly-lit portions are compressed, so that an output signal Sc′ is provided as shown in FIG. **1**.

Finally, when the signal Sb is applied as an input, the input-output characteristic becomes a linear function as shown by curve b in FIG. **2**, so that the output signal Sb′ is provided, and the latter is identical with the input signal Sb.

In order to optimize the output video signals Sa′ Sb′, and Sc′, the input-output characteristic must be changed continuously and automatically according to the information distribution of the input signals Sa, Sb, and Sc. Because the picture information distribution is akin to the proportional amount of bright and dimly-lit portions of the picture, the information distribution can be easily obtained by detecting the average picture level (APL) of the input signals Sa, Sb, and Sc. In other words, when the amount of informationn near the black level B is great, as in the signal Sa, the APL will be low. By contrast, when the amount of information near the peak white level W is great, as in the signal Sc, the APL will be high. Because the Sb has information distributed uniformly between the back B and peak white level W, the signal Sb will have an APL of about 50%.

Accordingly, the input-output characteristic a of FIG. **2** is selected for low APL values, the characteristic c is selected for high APL values, and the linear characteristic b is selected when the APL is at or near its optimum level of 50%. Further, when the APL is at some intermediate level, the input-output characteristic can be selected intermediate the curves a and b or intermediate the curves b and c.

Throughout the following description of various embodiments of this invention, common elements will be identified with the same reference characters, and a description of such elements will be provided only with respect to the embodiment with which they are first introduced.

One embodiment showing the basic construction of a correction circuit according to this invention is illustrated in FIG. **3**. A video input information signal Si is furnished to an input of a variable correction circuit **10** and is also furnished to an APL detecting circuit **20**. The latter detects the APL of the input signal Si and provides a control signal to a control input of the variable correction circuit **10**. The variable correction circuit **10** automatically adjusts its input-output character-

istic in response to the control signal, and thus also, the input-output characteristic varies as a function of the detected APL. Consequently, the variable correction circuit provides an optimized output signal S_O.

Another example of the control circuit of this invention is shown in FIG. **4**, wherein the output signal S_O is fed back to the APL detecting circuit **20**, so that the input-output characteristic of the variable correction circuit **10** is determined in accordance with the average picture level of the output signal S_O.

The open-loop configuration of FIG. **3** has the advantage of fast and reliable response to changes in APL, while the closed-loop configuration of FIG. **4** has the advantage of superior accuracy in correcting the brightness characteristic of the video signal.

Practical input-output characteristics of the variable correction circuit are illustrated in FIG. **5**, in which the absissa represents an input while the ordinate represents an output X^γ. Here, the input and output remain between values of "0" (representing the black level) and "1" (representing the peak white level). The value of γ is changed according to the detected APL value. For example, when the APL is detected to be below 50%, γ is selected as $\delta = \frac{1}{2}$, and the output becomes $\sqrt{X}$; when the detected APL is at 50%, γ is selected as unity, and the output becomes X; and when the detected APL is above 50%, γ is selected as $\gamma = 2$, and the outout becomes X^2. For extreme values of the detected APL, γ can be selected as $\gamma \pm \frac{1}{3}$ so that the output becomes $\sqrt[3]{X}$ when the detected APL is extremely low, and $\gamma = 3$ so that the output becomes X^3 when the detected APL is extremely high.

A practical embodiment of the correction circuit of this invention is shown in FIG. **6**, and the details thereof are illustrated in FIG. **7**. In this embodiment, the variable correction circuit **10** is composed of a first correction circuit **11** having an input-output characteristic of $\gamma = \frac{1}{2}$ (i.e., a square-root circuit with an output $\sqrt{X}$), and a second correction circuit **12** having an input-output characteristic of $\gamma = 2$ (i.e., a squaring circuit with an output X^2). When the input video signal S_I is applied to respective inputs of each of the first and second correction circuits **11** and **12**, the latter in turn provide first and second corrected video signals which are proportional to $\sqrt{X}$ and X^2, respectively. A summing circuit **13** combines the first and second corrected video signals in proportional amounts depending on the value of the control signal from the APL detector **20**. Thus, when the APL is low, only the first corrected video signal $\sqrt{X}$ is provided. When the APL is high, only the second corrected video signal $\sqrt{X}$ is provided. When the APL is determined to be 50%, the first and second corrected video signals are provided in equal amounts so that the output signal S_O has the output characteristic

$$\frac{\sqrt{X} + X^2}{2},$$

that is, the output signal S_O will be approximately the same as the input signal S_I. It should be noted that for $0<X<1$, the value of the expression

$$\frac{\sqrt{X} + X^2}{2}$$

will be very close to the value $X(\gamma=1)$, and the two expressions will have the same value at 0, 1, and approximately 0.38.

In the practical circuit shown in FIG. **7**, the first correction circuit **11** includes a constant current source **14**; a diode-connected transistor Q_1, having its base and collector connected together to receive an input signal current I_i; an auxiliary transistor Q_2 having its collector coupled to the emitter of the transistor Q_1 and its emitter connected to ground; an input transistor Q_3 having its collector connected to a voltage source V_{CC}, its base connected to the emitter of the transistor Q_1, and its emitter coupled to the constant current source **14** and also to the base of the transistor Q_2; and an output transistor Q_4 having its base connected to the base of transistor Q_3 and the emitter of the transistor Q_1, and its collector providing the first output correction signal current $\sqrt{I_i}$. A diode-connected transistor Q_5 is connected between the emitter of the transistor Q_4 and ground.

The second correcting circuit **12** includes a constant current source **15**, and input transistor Q_6 having its base connected to receive the input signal S_I and its collector connected to the voltage source V_{CC}; a diode-connected transistor Q_7 having its base and collector connected to the emitter of the transistor Q_6 and its emitter connected to the constant current source **15**; and an output transistor Q_8 having its base connected to the emitter of the transistor Q_7, its emitter connected to ground, and its collector providing a second output correction signal current I_i^2.

The summing circuit **13** is formed of a load resistor **16** connected to the voltage source V_{CC}; a first transistor Q_9 having its collector connected to the voltage V_{CC} and its base connected to receive the control signal from the APL detecting circuit **20**; a second transistor Q_{10} having its collector connected to the load resistor **16** and its emitter, together with the emitter of the first transistor Q_9 connected to the collector of the output transistor Q_4. The summing circuit **13** also includes a third transistor Q_{11} having its collector connected to the voltage source V_{CC}, and its base together with the base of the transistor Q_{10} biased at a predetermined level. Also included is a fourth transistor Q_{12} having its collector connected to the load resistor **16**, its base connected to receive the control signal from the APL detecting circuit **20**, and its emitter, together with the emitter of the third transistor Q_{11} connected to the collector of the output transistor Q_8. An output terminal **17** is connected to the junction of the load resistor **16** with the collectors of the transistors Q_{10} and Q_{12}.

In this embodiment, the APL detecting circuit **20** is a low-pass filter composed of a resistor and a capacitor.

The specific operation of the embodiment depicted in FIG. **7** is explained as follows:

In this circuit, if equal constant currents I are provided from each of the constant current sources **14** and **15**, the base-emitter forward voltages of the transistors Q_1 to Q_8 are represented as V_{BE1} to V_{BE8}, respectively, and the transistors Q_1 to Q_8 have respective collector currents I_1 to I_8, respectively, the following relationship is obtained:

$$V_{BE2} + V_{BE3} = V_{BE4} + V_{BE5} \tag{1}$$

As is well known, the base-emitter forward voltage V_{BE} of a transistor can be expressed as a function of its collector current I_c and the saturation current I_s thereof according to the following equation:

$$V_{BE}=KT/g \ln Ic/I_s \quad (2)$$

where g is an electric charge constant relating to the number of charge carriers in the base-emitter junction, K is the Boltzmann constant, and T is a constant having units of temperature. Accordingly, the currents of the transistors Q_2 to Q_5 will have the relationship

$$I_2 \cdot I_3 = I_4 \cdot I_5 \quad (3)$$

In this circuit, I_2 is equal to the input current I_i, I_3 is equal to the current I of the constant current source **14**, and I_4 is equal to I_5, so that the latter currents can be expressed as $I_4=I_5=I_m$. Accordingly, the following relationship results:

$$I_i \cdot I = I_m^2 \quad (4)$$

that is,

$$I_m = \sqrt{I} \cdot \sqrt{I_i} \quad (5)$$

If it is assumed that the current I of the constant current source **14** is unity, then I=1, and

$$I_m = \sqrt{I_i} \quad (6)$$

Thus, the first correction circuit **11** has a gamma of ½.

At the same time, in the second correction circuit **13**, the base-emitter voltages of the transistors Q_6, Q_7, and Q_8 can be expressed

$$V_{BE1}+V_{BE3}+V_{BE2}=V_{BE6}+V_{BE7}+V_{BE8} \quad (7)$$

and the respective collector currents can be expressed as

$$I_1 \cdot I_3 \cdot I_2 = I_6 \cdot I_7 \cdot I_8 \quad (8)$$

In addition, because the currents I_1 and I_2 are each equal to the input current I_i, and the currents I_3, I_6, and I_7 are each identical with the current I from the constant current source **15**, if the current I_8 is expressed an I_n, the following relationship results:

$$I_i^2 \cdot I = I^2 \cdot I_n \quad (9)$$

or

$$I_n = (1/I) \cdot I_i^2 \quad (10)$$

thus, if, as aforesaid, the current I is unity, then

$$I_n = I_i^2 \quad (11)$$

Consequently, the second correction circuit **12** has a gamma of 2.

In the summing circuit **13**, a current $k \cdot \sqrt{I_i}$ flows through the collector of the second transistor Q_{10} while a current of $(1-k)I_i^2$ flows through the collector of the fourth transistor Q_{12}, where k is a positive number less than unity which is determined according to the average picture level voltage from the APL circuit **20**. As a result, an output current I_O flows through the load resistor **16**, and can be expressed as follows:

$$I_0 = k\sqrt{I_i} + (1-k)I_i^2 \quad (12)$$

In other words, when the APL is detected to be extremely low, the transistors Q_9 and Q_{12} are rendered nonconductive so that the constant k is unity, and the output current I_O equals the current $\sqrt{I_i}$ from transistor Q_4. When the APL is approximately 50%, k=½, and the output current I_O can be expressed.

$$I_0 = \frac{\sqrt{I_i} + I_1^2}{2}.$$

When the APL is determined to be high, the second and third transistors Q_{10} and Q_{11} are rendered nonconductive so that the constant k=0 and I_O can be expressed

$$I_0 = \sqrt{I_i}.$$

Of course, for intermediate values of the detected APL, the constant k will take on intermediate values of gamma so that the output signal S_O will provide a video picture of optimum contrast.

Another embodiment of the correction circuit according to this invention is illustrated in FIG. **8**. In this embodiment, the variable correction circuit **10** is formed of the squaring circuit **12** having its input coupled to receive the input signal S_i, a polarity inverter **18** coupled to the output of the squaring circuit **12**, and the summing circuit **13** connected to combine the output of the squaring circuit **12** with an inverted replica thereof provided from the polarity inverter **18**. Also in this embodiment, an adder **19** is included to combine the input video signal with the resultant video signal provided from the summing circuit **13**.

The summing ratio of the corrected signal from the squaring circuit **12** and the inverted replica thereof is changed according to the control signal furnished from the APL detector **20**. Since the output of the polarity inverter **18** is expressed as $-X^2$, the output of the summing circuit **13** can be expressed as

$$mX^2-(1-m)X^2=(2m-1)X^2$$

so that the output signal from the adder **19** can be expressed as

$$X+(2m-1)X^2.$$

Hence, the input-output characteristic of the variable correction circuit **10** is changed according to the value of m in accordance with the detected average picture level. However, in order to maintain the brightness range of the output video signal S_O as a constant, a peak automatic gain control circuit **30** is coupled from the output of the adder **19** back to a point in advance of the variable correcting circuit **10**.

It should be noted that in this embodiment if the value of m is selected as ¼, the variable correction circuit **10** will have a gamma approximately ½, if the value of m is selected as ½, the gamma will be unity, and if the value of m is selected as 1, the gamma will be 2.

FIG. **9** illustrates a three-tube type color television camera incorporating a correction circuit according to the present invention. In this camera, an optical system

40 separates the image into red, green, and blue images which are incident on respective red, green, and blue image pickup tubes 50R, 50G, and 50B. As a result, the latter provide respective red, green, and blue color signals. These color signals are provided to a matrix circuit 60 which then derives from them a luminance signal and supplies the same to the APL detector 20. In this embodiment, respective variable correction circuits 10R, 10G, and 10B are provided to control the brightness of the corresponding red, green, and blue color signals. The control signal from the APL detector 20 is provided to each of the vertical correction circuits 10R, 10G, and 10B to control their respective input-output characteristics. Then, the corrected red, green, and blue color signals from the circuits 10R, 10G, and 10B are supplied through respective γ-correction circuits 70R, 70G, and 70B to an NTSC encoder 80, and the latter provides an encoded composite color video signal at an output terminal 90 thereof.

If instead of a plural-tube camera, a single-tube type color camera is employed, in which the luminance signal is separated, the average picture level of the luminance signal can be detected without the necessity of employing the matrix circuit 60.

A television receiver incorporating a correction circuit according to this invention is illustrated in FIG. 10. In this receiver, a composite color video signal applied to an input terminal 100 thereof is separated in a filter circuit 110 into a luminance component Y and a chrominance component C. The luminance component Y is furnished through a luminance signal processing circuit 120 to a matrix circuit 130, and is also furnished to the APL detector 20. The chrominance component C is furnished to color demodulator 140 which then supplies a pair of color difference signals to the matrix circuit 130. The latter then provides primary color signals R, G, and B to a color cathode ray tube 150. In this receiver, respective variable correction circuits 10R, 10G, and 10B are provided between the matrix circuit 130 and respective cathodes 150R, 150G, and 150B of the color cathode ray tube 150. Here, the separated red, green, and blue color signals are adjusted in brightness according to the average luminance level detected by the APL detector 20.

Another embodiment of this invention is illustrated in FIG. 11, in which the luminance component and the chrominance component are not separated, as they are in the embodiment of FIG. 10. In this embodiment, the composite color video signal is applied from the input terminal 100 to a clamp circuit 210 and thence to the variable correction circuit 10. The composite color video signal is also supplied to a subcarrier trap circuit 220, which blocks the chrominance component modulated on the subcarrier, so that only the luminance signal and the synchronizing pulse are passed. The synchronizing pulse is separated out therefrom in a synch separator 230 and is furnished to the clamp circuit 210 so that the latter can clamp the video signal to the pedestal level of the synchronizing pulse. The luminance component is furnished from the subcarrier trap 220 through a synch signal slice circuit 240 to the APL detector 20. A corrected composite color video signal is then applied from the variable correction circuit 10 to an output terminal 250. In this embodiment, the variable correction circuit 10 has an input-output characteristic that varies as a function of the control signal from the APL detector 20 during the line scanning portion of the video signal, but has a linear input-output characteristic

($\gamma=1$) during the occurrence of the synchronizing pulse.

Another embodiment of the correction circuit of this invention is illustrated in FIG. 12. It should be appreciated that the embodiment of FIG. 12 is a variation of the embodiment of FIG. 11. In this embodiment, the luminance and chrominance components are not separated from one another, but the synchronizing pulse is separated out and is treated separately. Here, a video separator 260 is coupled to the input terminal 100 so that only the luminance and chrominance components are furnished to the clamp circuit 210. The synch separator 230 is coupled in advance of the video separator 260, and the separated synchronizing pulse is furnished therefrom to the clamp circuit 210 and also to an adder circuit 270 disposed after the variable correction circuit 10. The composite color video signal, without the synchronizing pulse, is applied to the clamp circuit 210 where it is clamped to the pedestal level of the synchronizing pulse from the synch separator 230, and the thus-clamped color video signal is supplied to the variable correction circuit 10. The clamped color video signal is also supplied through the subcarrier trap circuit 220 to the APL detector 20 which detects the average picture level of the luminance component. The APL detector 20 then furnishes a control signal to the variable correction circuit 10 to control its input-output characteristic. Then, the corrected color video signal from the variable correcting circuit 10 is combined in the adder circuit 270 with the separated synchronizing pulse, so that a finally corrected composite color video signal is provided at the output terminal 250.

Yet another video receiver incorporating the correction circuit according to this invention is illustrated in FIG. 13. This video receiver combines the features of this invention with a circuit for dynamically controlling the amplitude of the video signal according to the picture contents, i.e., a so-called dynamic picture control circuit. Examples of such a dynamic picture control circuit are disclosed in U.S. Pat. No. 4,403,254, issued Sept. 6, 1983, and U.S. Pat. No. 4,298,885, issued Nov. 3, 1981, both of which have a common assignee herewith.

As illustrated in FIG. 13, the separated luminance signal is furnished from the filter 110 to a luminance gain control circuit 170Y and is then furnished to a luminance correction circuit 10Y. The latter is formed in general like the embodiment of FIG. 8, and includes a squaring circuit 12Y, a gain control circuit 13Y, and an adder circuit 19Y. A corrected luminance signal is furnished from the adder circuit 19Y through a luminance processing circuit 120 to the matrix circuit 130. The luminance component Y is also furnished from the gain control circuit 170Y to the APL detector 20 which then detects the average luminance component. The chrominance component C is furnished through an automatic chroma control (ACC) circuit 160 to a chrominance gain control circuit 170C, and thence to a chrominance correcting circuit 10C. This circuit 10C is basically similar to circuit 10Y and to the embodiment of FIG. 8, and includes a squaring circuit 12C, a gain control circuit 13C, and an adder circuit 19C. The corrected chrominance signal is then furnished from the adder circuit 19C to the color demodulator 140 which provides demodulated color difference signals to the matrix circuit 130.

The matrix circuit 130 provides decoded primary color signals R, G, and B to the cathodes 150R, 150G,

and **150B** and also to a minimum value detecting circuit **180**, which here includes diodes having their cathodes connected to the cathodes **150R**, **150G**, and **150B** of the cathode ray tube **150** and having their anodes connected to a peak detecting circuit **190**. The output of the peak detecting circuit **190** then controls the gain of the gain control circuits **170Y** and **170C**.

In this embodiment, the control signal from the APL detector **20** is furnished to both the gain control circuit **13Y** and the gain control circuit **13C** of the respective luminance and chrominance variable correcting circuits **10Y** and **10C**.

In each of the above embodiments of this invention, the brightness of a video signal is automatically controlled according to the information carried within the video signal, thereby providing an optimum contrast ratio to that portion of the video picture having the greatest amount of information. As a result, according to this invention, it is possible to provide a reproduced picture which is natural and pleasing to the eye, and which has sufficient contrast so that the picture is neither harsh nor washed out.

Although certain preferred embodiments of this invention have been described in detail herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein by persons skilled in the art without departing from the scope or spirit of the invention as defined in the appended claims.

What is claimed is:

1. A control circuit for controlling the brightness of a video signal that fluctuates between a peak dark level and a peak bright level about an average brightness level comprising:

brightness controlling means having a signal input to which the video signal is applied as an input video signal and a signal output from which an output video signal is provided, said brightness controlling means being operable by a control signal for controlling the brightness of the video signal so that respective portions of said output video signal corresponding to portions of the input video signal at said peak dark level and at said peak bright level are provided substantially at said peak dark and bright levels while the average picture level of said output video signal is provided at a predetermined optimum level;

average picture level detecting means for detecting the average brightness level of at least one of said input and output video signals and providing said control signal in response to the detected average brightness level; and

a variable gamma correction circuit included in said brightness controlling means and having an input-output characteristic such that for the input video signal having a level proportional to a value X, where X is in the range $0 \leqq X \leqq 1$, said video signal is provided at a level proportional to a value X^{γ}; and the value of γ is automatically determined in response to the control signal from said average picture level detecting means.

2. A control circuit according to claim **1**; wherein said average picture level detecting means is connected to receive said input video signal in advance of said brightness controlling means to provide said control signal as a function of the average brightness level of said input video signal.

3. A control circuit according to claim **1**; wherein said average picture level detecting means is connected to receive said output video signal from said brightness controlling means to provide said control signal as a function of the average brightness level of said output video signal.

4. A correction circuit according to claim **1**; wherein said variable gamma correction circuit includes means for selecting the value of γ to be a number whose magnitude is less than unity when said average brightness level is detected to be less than said predetermined optimum level, to be unity when said average picture level is detected to be substantially at said predetermined optimum level, and to be a number greater than unity when said average brightness level is detected to be greater than said predetermined optimum level.

5. A control circuit according to claim **4**; wherein the value of γ is selected to be $\frac{1}{2}$ and 2, respectively when said average brightness level is detected to be less than and greater than said predetermined optimum level.

6. A control circuit for controlling the brightness of a video signal that fluctuates between a peak dark level and a peak bright level about an average brightness level comprising:

brightness controlling means having a signal input to which the video signal is applied as an input video signal having a level proportional to a value X, where X is in the range $0 \leqq X \leqq 1$, and a signal output from which an output video signal is provided, said brightness controlling means being operable by a control signal for controlling the brightness of the video signal so that respective portions of said output video signal corresponding to portions of the input video signal at said peak dark level and at said peak bright level are provided substantially at said peak dark and bright levels while the average picture level of said output video signal is provided at a predetermined optimum level; said brightness controlling means including first correction circuit means having an input-output characteristic such that a first corrected video signal is provided at a level proportional to $\sqrt{X}$, second correction circuit means having an input-output characteristic such that a second corrected video signal is provided at a level proportional to X^2 and summing circuit means for combining said first and second corrected video signals in relative amounts depending upon said control signal so that the combined first and second corrected video signals are provided as said output video signal; and

average picture level detecting means for detecting the average brightness level of said input video signal and providing said control signal in response to the detected average brightness level.

7. A control circuit according to claim **6**; wherein said first correction circuit means includes a constant current source, an input transistor having an input electrode coupled to receive said input video signal and an output electrode coupled to said constant current source, an auxiliary transistor having a control electrode coupled with the output electrode of the input transistor and current carrying electrodes respectively coupled to the control electrode of the input transistor and to a reference point; and an output transistor having a control electrode coupled to the control electrode of said input transistor and an output electrode providing said first corrected video signal.

8. A control circuit according to claim 7; wherein said first correction circuit means further includes a diode coupled in advance of the control electrode of said input transistor; and wherein said second correction circuit means includes a constant current source, an input transistor having a control electrode coupled to receive said input video signal and an output electrode, a diode having one electrode coupled to the output electrode of the input transistor and another electrode coupled to said constant current source, and an output transistor having a control electrode coupled to said other electrode of said diode and an output electrode providing said second corrected video signal.

9. A control circuit according to claim 6; wherein said summing circuit means includes a load impedance; a voltage source; a first transistor having a control electrode coupled to receive said control signal, one current-carrying electrode coupled to said voltage source, and another current-carrying electrode coupled to receive said first corrected video signal; a second transistor having a control electrode, an input electrode coupled to said another current-carrying electrode of said first transistor, and an output electrode coupled to said load impedance; a third transistor having a control electrode, one current-carrying electrode coupled to said voltage source and another current-carrying electrode coupled to receive said second corrected video signal; means biasing the control electrodes of said second and third transistors to a predetermined level; a fourth transistor having a control electrode coupled to receive said control signal, an input electrode coupled to said other current carrying electrode of said third transistor, and an output electrode coupled to said load impedance; and output means coupled to said output impedance to provide said output video signal.

10. A control circuit for controlling the brightness of a video signal that fluctuates between a peak dark level and a peak bright level about an average brightness level comprising:

brightness controlling means having a signal input to which the video signal is applied as an input video signal and a signal output from which an output video signal is provided, said brightness controlling means being operable by a control signal for controlling the brightness of the video signal so that respective portions of said output video signal corresponding to portions of the input video signal at said peak dark level and at said peak bright level are provided substantially at said peak dark and bright levels while the average picture level of said output video signal is provided at a predetermined optimum level; said brightness controlling means including correction circuit means having an input terminal to which said input video signal is applied and an output terminal at which a corrected video signal is obtained, the latter being substantially proportional to the square of the input video signal, polarity inverter means coupled to the output terminal of the correction circuit means for providing an inverted version of said corrected video signal, summing circuit means for combining said corrected video signal and the inverted version thereof in relative amounts depending upon said control signal to provide a resultant video signal and adder means for combining the input video signal with said resultant video signal to produce said output video signal; and

average picture level detecting means for detecting the average brightness level of said input video signal and providing said control signal in response to the detected average brightness level.

11. A control circuit according to claim 10; further comprising peak automatic gain control circuit means for controlling the strength of the input video signal in response to at least one peak value of said output video signal.

12. A color television camera providing a composite color video signal comprising a plurality of pickup tubes each responsive to light of a respective primary color to produce a corresponding primary-color signal that fluctuates between a peak dark level and a peak bright level about an average brightness level; average picture level detecting means for detecting the average brightness level of the composite color video signal and providing a control signal in response to such detected average brightness level; a plurality of variable correction circuits each coupled to a respective pickup tube for processing a respective primary color signal, each such variable correction circuit being coupled to receive said control signal and having an input-output characteristic such that for the associated respective primary-color signal having a level proportional to a value X, where X is in range $0 \leqq X \leqq 1$, said variable correction circuit provides an output signal substantially proportional to a value X^{γ}, where the value γ is automatically determined in response to the control signal from the average picture level detecting means; and encoding means coupled to receive the output signals from said variable correction circuits for providing said composite color video signal as a brightness-corrected composite color video signal.

13. A color television camera according to claim 12; wherein said composite color video signal includes a luminance component; and said average picture level detecting means includes a matrix circuit having inputs coupled to said plurality of pickup tubes and an output providing said luminance component, and also includes average luminance level detecting means coupled to said matrix circuit and responsive to said luminance component for providing said control signal.

14. A control circuit for controlling the brightness of a video signal in a color television display apparatus having a color display tube providing a color video picture in response to a plurality of primary color signals, and in which a chrominance signal and a luminance signal that varies between a black level and a peak white level about an average brightness level are combined to form said plurality of primary color signals, comprising

average picture level detecting means coupled to receive the luminance signal for detecting the average brightness level of said luminance signal and providing a control signal in response to the detected average brightness level; and a plurality of variable correction circuits each operative upon a respective primary color signal and disposed in advance of said color display tube, each such variable correction circuit being coupled to receive said control signal and having an input-output characteristic such that for the associated respective primary-color signal having a level proportional to a value X, where X is in the range $0 \leqq X \leqq 1$, said variable correction circuit provides to the associated respective beam-generating device, an output signal that is substantially propor-

tional to a value X^γ, where the value of γ is automatically determined in response to said control signal.

15. A correction circuit for controlling the brightness of a composite color video signal having a luminance component that fluctuates between a black level and a peak white level about an average luminance level, a chrominance component, and a synchronizing pulse with a pedestal portion, comprising clamping means for establishing the black level of said video signal as a function of said pedestal portion; means for providing said synchronizing pulse to said clamping means; average picture level detecting means for providing a control signal in response to the average luminance level of said luminance component; and brightness controlling means coupled to receive said control signal and having a signal input to which at least said luminance and chrominance components are applied and a signal output from which an output composite video signal is obtained, for controlling the brightness of the composite video signal so that respective portions of said output composite video signal corresponding to portions of the luminance component at said black level and at said peak white level are provided substantially at said black and peak white levels, while said output composite video signal has an average picture level that is provided at a predetermined optimum level.

16. A correction circuit according to claim 15; wherein said brightness controlling means has an input-output characteristic that varies as a function of said control signal between occurrences of said synchronizing pulse but has a constant input-output charcteristic during occurrence of said synchronizing pulse.

17. A correction circuit according to claim 16; further comprising synch signal slicing means in advance of said average picture level detecting means for blocking said synchronizing pulse.

18. A correction circuit according to claim 15; further comprising separating means in advance of said clamping means for passing thereto said composite color video signal without said synchronizing pulse, said means for providing said synchronizing pulse having an input coupled in advance of said separating means; and wherein said brightness controlling means includes means for controlling the brightness of the clamped luminance and chrominance components to provide a corrected signal and adder means for combining the corrected signal with the synchronizing pulse to produce said output composite video signal.

19. A color video display apparatus to which is applied a composite color video signal including a chrominance component and a luminance component that fluctuates between a black level and a peak white level about an average brightness level comprising separating means for separating said luminance component and said chrominance component from said composite color video signal; average picture level detecting means having an input coupled to receive the separated luminance component for providing a control signal in response to the detected average brightness level; variable luminance component controlling circuit means having an input to receive the separated luminance component, a signal output from which a corrected luminance component is provided, and a control input to receive said control signal, for controlling the brightness of the separated luminance component so that respective portions of the corrected luminance component corresponding to portions of the separated luminance component at said black and peak white levels are provided substantially at said black and peak white levels, while the average brightness level of said corrected luminance component is provided substantially at a predetermined optimum level; variable chrominance component controlling circuit means having an input to receive the separated chrominance component, a signal output from which a corrected chrominance component is provided, and a control input to receive said control signal, for controlling the strength of the separated chrominance component, and having an input-output characteristic that varies as a function of said control signal; processing circuit means to which said corrected luminance and chrominance components are applied for producing a plurality color signals; and display means for producing a picture in response to said primary color signals.

20. A color video display apparatus according to claim 19; further comprising minimum value detecting means for detecting the minimum among the levels of said plurality of primary color signals; peak detecting means for detecting the peak value of such detected minimum level and providing a gain control signal in response thereto; luminance gain control means interposed between said separating means and said variable luminance component controlling circuit means for controlling the strength of said separated luminance component in dependence on said gain control signal; and chrominance gain control means interposed between said separating means and said variable chrominance component controlling means for controlling the strength of said separated chrominance component in dependence on said gain control signal.

21. A color video display apparatus according to claim 20; further comprising an automatic chroma control circuit interposed between said separating means and said chrominance gain control means.

* * * * *

United States Patent [19]
Carlson et al.

[11] Patent Number: 4,523,230
[45] Date of Patent: Jun. 11, 1985

[54] **SYSTEM FOR CORING AN IMAGE-REPRESENTING SIGNAL**

[75] Inventors: **Curtis R. Carlson; Edward H. Adelson**, both of Princeton; **Charles H. Anderson**, Rocky Hill, all of N.J.

[73] Assignee: **RCA Corporation**, Princeton, N.J.

[21] Appl. No.: **663,152**

[22] Filed: **Oct. 22, 1984**

[30] **Foreign Application Priority Data**

Nov. 1, 1983 [GB] United Kingdom 8329109

[51] **Int. Cl.**[3] **H04N 5/14**; H04N 5/21
[52] **U.S. Cl.** **358/167**
[58] **Field of Search** .... 358/160, 163, 166, 167, 358/905, 21 R, 36; 382/49, 54

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,163,258 7/1979 Ebihara 358/167
4,442,454 4/1984 Powell 358/167
4,463,381 7/1984 Powell 358/167

Primary Examiner—Tommy P. Chin
Attorney, Agent, or Firm—Joseph S. Tripoli; George E. Haas; George J. Seligsohn

[57] **ABSTRACT**

Noise reduction is achieved, without the introduction of noticeable artifacts in the displayed image, using (1) a non-ringing, non-aliasing, localized transfer, octave-band spectrum analyzer for separating the video signal representing the image into subspectra signals, (2) separate coring means for one or more of the analyzed subspectra signals, and (3) then a synthesizer employing one or more non-ringing, non-aliasing filters for deriving an output image-representing signal from all of the subspectra signals.

24 Claims, 8 Drawing Figures

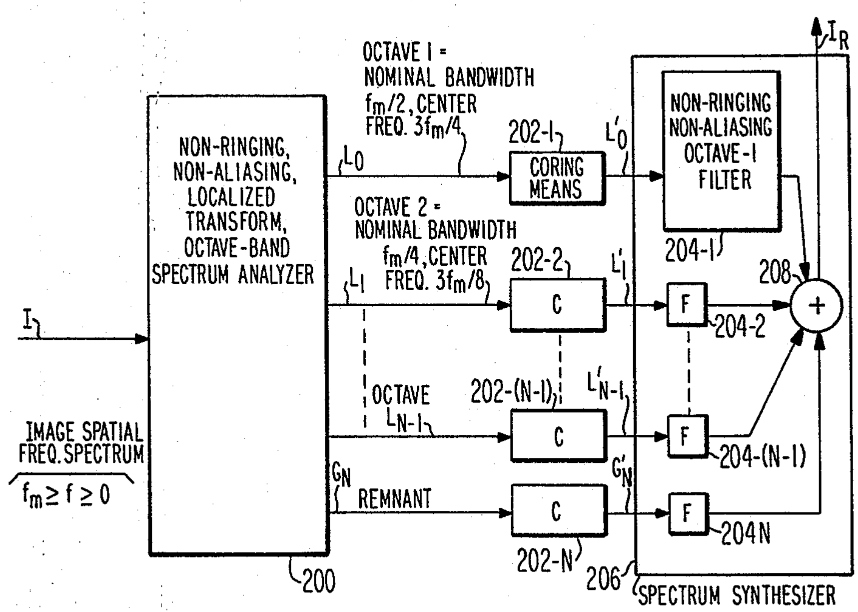
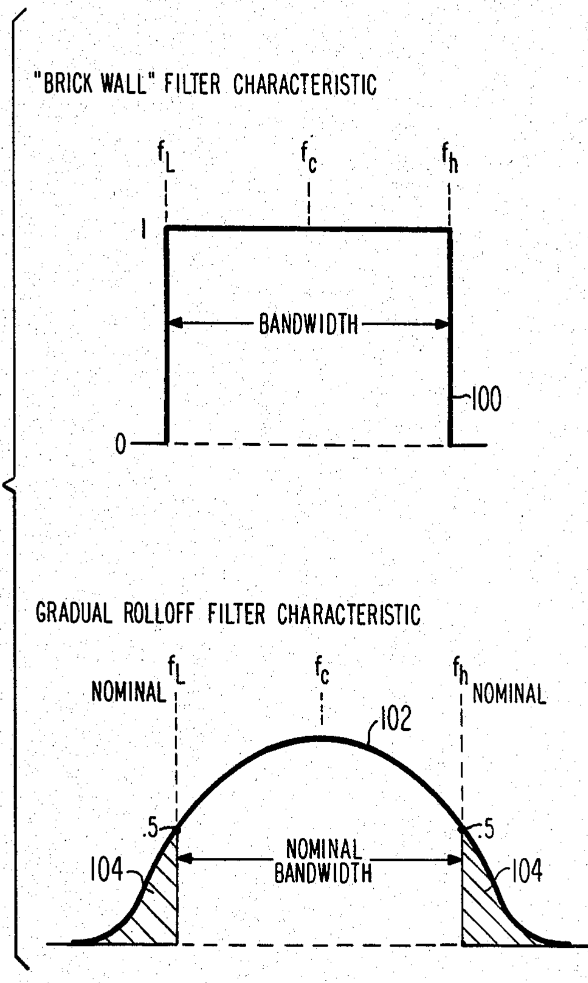
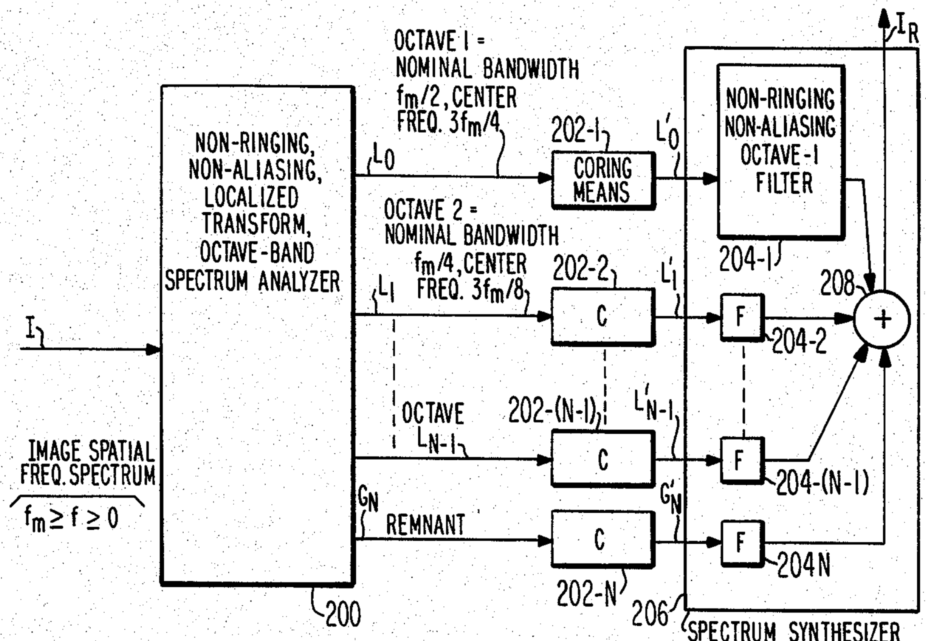


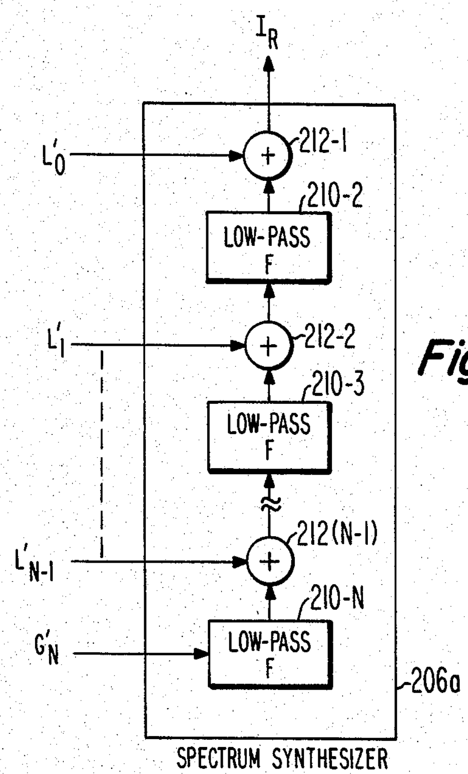
Fig. 1


"BRICK WALL" FILTER CHARACTERISTIC
fL
fc
fh
1
BANDWIDTH
100
0
GRADUAL ROLLOFF FILTER CHARACTERISTIC
NOMINAL
fL
fc
fh
NOMINAL
102
.5
.5
104
NOMINAL BANDWIDTH
104



OCTAVE 1 = NOMINAL BANDWIDTH fm/2, CENTER FREQ. 3fm/4
NON-RINGING, NON-ALIASING, LOCALIZED TRANSFORM, OCTAVE-BAND SPECTRUM ANALYZER
NON-RINGING NON-ALIASING OCTAVE-1 FILTER
CORING MEANS
OCTAVE 2 = NOMINAL BANDWIDTH fm/4, CENTER FREQ. 3fm/8
OCTAVE
REMNANT
IMAGE SPATIAL FREQ. SPECTRUM
fm ≥ f ≥ 0
SPECTRUM SYNTHESIZER
200
202-1
202-2
202-(N-1)
202-N
204-1
204-2
204-(N-1)
204N
206
208

Fig. 2



LOW-PASS F
212-1
212-2
212(N-1)
210-2
210-3
210-N
206a
SPECTRUM SYNTHESIZER

Fig. 2a

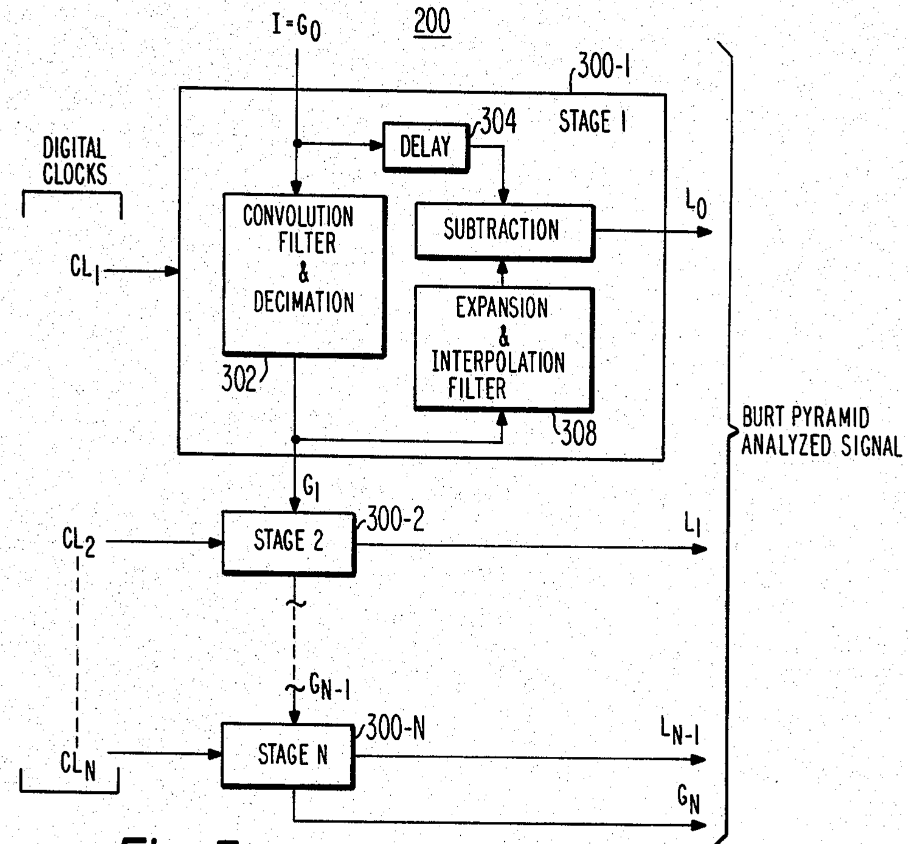


Fig. 3a
PRIOR ART

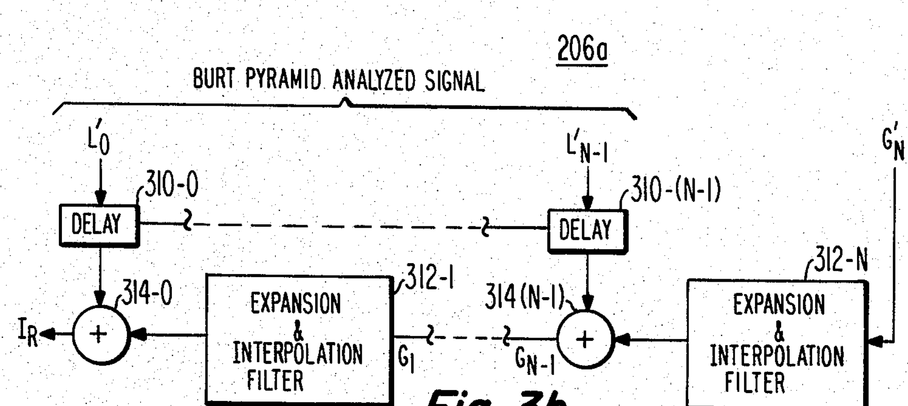


Fig. 3b
PRIOR ART

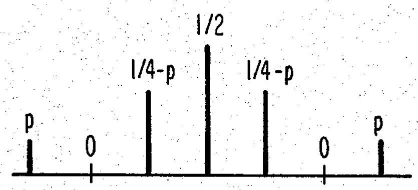


Fig. 4a

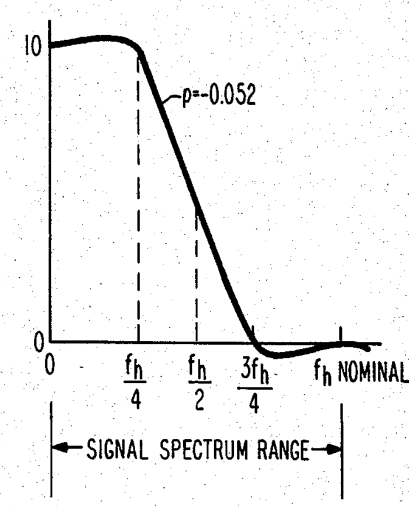


Fig. 4

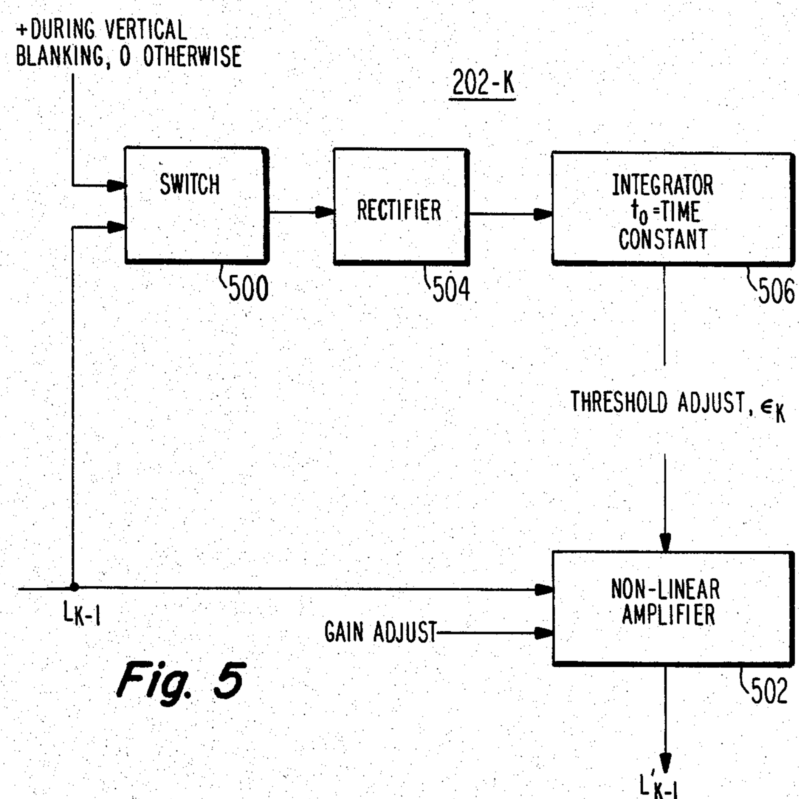


Fig. 5

SYSTEM FOR CORING AN IMAGE-REPRESENTING SIGNAL

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to an image-processing system employing coring techniques for reducing the noise component of an image-representing signal, such as a television video signal. More particularly, this invention relates to such a system which reduces this noise component without introducing any significant amount of aliasing or other spurious spatial frequency components into the image-representing signal.

2. Description of the Prior Art:

Coring is a well known technique for reducing the noise component of an image-representing signal. Coring consists of selectively passing only those portions of the image-representing signal which have an absolute amplitude level exceeding a selected threshold magnitude. Coring is a non-linear process that inherently introduces spurious harmonic and intermodulation spatial frequency components into the image-representing signal. The relative power of these spurious spatial frequency components increase as the selected threshold magnitude increases. Therefore, the selection of the coring threshold magnitude is a tradeoff between that which is high enough to substantially reduce the noise component and yet is not so high as to introduce an intolerable amount of spurious spatial frequency components.

The noticeability of a noise component, to an observer of a displayed image derived from an image-representing signal, depends on both (1) the spatial frequency spectrum of the noise component relative to the spatial frequency spectrum of the signal component of the displayed image and (2) on the operation of the human visual system in perceiving noise.

It has been found that human visual system appears to compute a primitive spatial-frequency decomposition of luminous images, by partitioning spatial frequency information into a number of contiguous, overlapping spatial-frequency bands. Each band is roughly an octave wide and the center frequency of each band differs from its neighbors by roughly a factor of two. Research suggests that there are approximately seven bands or "channels" that span the 0.5 to 60 cycle/degree spatial-frequency range of the human visual system. The importance of these findings is that spatial frequency information more than a factor of two away from other spatial frequency information will be independently processed by the human visual system. It has been further found that the spatial-frequency processing that occurs in the human visual system is localized in space. Thus, the signals within each spatial-frequency channel are computed over small subregions of the image. These subregions overlap each other and are roughly two cycles wide at a particular frequency. If a sine wave grating image is employed as a test pattern, it is found that the threshold contrast-sensitivity function for the sine wave grating image rolls-off rapidly as the spatial frequency of the sine wave grating image is increased. That is, high spatial frequencies require high contrast to be seen (≃20% at 30 cycle/degree) but lower spatial frequencies require relatively low contrast to be seen (≃0.2% at 3 cycle/degree). It has been found that the ability of the human visual system to detect a change in the contrast of a sine wave grating image that is above threshold also is better at lower spatial frequencies than at higher spatial frequencies. Specifically, an average human subject, in order to correctly discriminate a changing contrast 75% of the time, requires roughly a 12% change in contrast for a 3 cycle/degree sine wave grating, but requires a 30% change in contrast for a 30 cycle/degree grating.

Based on the operation of the human visual system, it becomes clear that a relatively high signal-to-noise (S/N) ratio within an octave spatial frequency band tends to mask the noise (i.e. the noise becomes unnoticeable to an observer) and that this masking effect is more effective for a higher spatial frequency octave than it is for a lower spatial frequency octave. This is true because of the relative decrease in both contrast sensitivity and change-in-contrast sensitivity of the human visual system at higher spatial frequencies. On the other hand, a relatively small high spatial frequency noise component superimposed on a nearly uniform background, which is comprised of dc (zero) or very low spatial frequency video components, is easily noticed by the human visual system. This is significant because real-world images, for the most part, have a spatial frequency spectrum in two dimensions which contains a large amount of relatively low spatial frequency signal energy and only a small amount of high frequency signal energy. This makes any high spatial frequency noise particularly noticeable.

If only a single coring means is employed to core the entire spatial frequency spectrum of an input image-representing signal, the selected threshold magnitude is likely to be too small to satisfactorily reduce the noticeable noise component in one or more octave portions of this spatial frequency spectrum, while at the same time being so high in one or more other octave portions of this spatial frequency spectrum that an intolerable amount of spurious spatial-frequency component artifact is introduced in the displayed image.

This problem can be avoided by first spectrum analyzing the input image-representing signal into a plurality of contiguous subspectra bands, then separately coring each of these bands with a different appropriate selected threshold magnitude, and finally synthesizing these cored bands into a single output image-representing signal which is employed to derive the displayed image.

Reference is made to U.S. Pat. No. 4,442,454, which issued Apr. 10, 1984 to Powell, and is entitled "Image Processing Method Using a Block Overlap Transformation Procedure." This Powell patent discloses a spectrum analyzer for separating the spatial frequency spectrum of an applied sampled two-dimensional image-manifesting signal input into three contiguous subspectra. The spectrum analyzer disclosed in Powell includes predetermined direct transform networks for deriving a fine-detailed (relatively high spatial frequency) subspectrum output at the sampling density of the input signal, an intermediate detail (relatively intermediate spatial frequency) subspectrum output at a reduced sampling density, and a coarse detail (relatively low spatial frequency) subspectrum output at a further reduced sampling density. Each of the respective subspectra output signals from the analyzer is individually first cored and then operated on by an inverse transform network. An expand/interpolation filter is used to increase the sampling density of each of the coarse-detail and intermediate-detail subspectra back to the sampling density of the

fine-detail subspectrum, after which the respective cored subspectra signals are summed to derive an output image-representing signal used to provide a reduced-noise display of the represented image.

Powell is aware that image processing of image-representing signals, for the purpose of reducing noise, tends to result in some distortion of local image values (i.e. an artifact of the processing itself is generated that is noticeable in the display of the processed image). In fact, the block overlap transformation procedure of Powell is intended to prevent a noticeable boundary from existing between adjacent blocks in the displayed image. These boundaries are undesirable because they lead to a checkerboard appearance in the displayed image that is unacceptable for high quality image reproduction. Powell also realizes that some distortion of local image values necessarily results from the non-linear coring process, and that this produces an artifact that noticeably affects both the displayed image signal and the residue of unwanted noise. Nevertheless, Powell believes that such an artifact of the coring process has to be tolerated in order to realize the desired noise reduction.

SUMMARY OF THE INVENTION

The image processing system of the present invention permits any noise component originally present in the spectrum of an input image-representing signal to be reduced in the spectrum of the output image-representing signal without introducing any significant amount of aliasing or other spurious spatial frequency component in the spectrum of the output image-representing signal. Thus, the present invention does not require that noticeable artifacts of the processing itself be tolerated in order to realize the desired noise reduction.

More specifically, the image processing system of the present invention is comprised of a substantially non-ringing, non-aliasing, localized transform spectrum analyzer that is responsive to an input image-representing signal defined in at least one dimension of the represented image by a spectrum of spatial frequencies within a range extending from a maximum frequency f_m down to zero. The analyzer separates the input-signal spectrum in descending spatial frequency order starting from f_m into a group of one or more contiguous bandpass subspectra output signals each of which has a nominal bandwidth no greater than one octave within the f_m to zero range, and into a remnant subspectrum output signal containing all those spatial frequencies of the input signal spectrum which are below those contained in the lowest spatial frequency bandpass subspectrum output signal. The image processing system further comprises means for coring at least one of the bandpass subspectra output signals, thereby introducing spurious out-of-band spatial frequency components into each cored subspectrum output signal. Coupled to the analyzer through the coring means is a spectrum synthesizer that is responsive to all of the subspectra signals from the analyzer being applied thereto for deriving an output image-representing signal. This synthesizer is comprised of substantially non-ringing, non-aliasing filter means individually associated with the subspectrum of at least each cored signal that is lower than the highest spatial frequency bandpass output signal. The filter means individually associated with a subspectrum substantially removes at least those spurious frequency components therefrom which are above-band with regard to that subspectrum. The synthesizer is further comprised of means for summing all of the subspectra signals, including both any that has been cored and/or filtered and any that has been neither cored nor filtered, thereby to derive the aforesaid output image representing signal.

A practical implementation of the present invention, for operating in real time on an input video signal representing a scanned television image, may employ a so-called Burt Pyramid spectrum analyzer and Burt Pyramid synthesizer of a type disclosed in co-pending U.S. patent application Ser. No. 596,817, filed Apr. 4, 1984 by Carlson et al., and assigned to the same assignee as the present invention.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** comprises respective graphs comparing a "brickwall" filter characteristic to a gradual rolloff filter characteristic;

FIG. **2** is a functional block diagram of an idealized embodiment of the present invention;

FIG. *2a* illustrates an alternative embodiment of the spectrum synthesizer of FIG. **2**;

FIG. *3a* illustrates a Burt Pyramid spectrum analyzer which is useful in a practical implementation of the spectrum analyzer of FIG. **2**;

FIG. *3b* illustrates a Burt Pyramid synthesizer which is useful in a practical implementation of the spectrum synthesizer of FIG. *2a;*

FIG. **4** is a graph of the baseband envelope of a seven multiplier-coefficient kernel weighting function having the respective values shown in FIGS. **4** and *4a* of the convolution or interpolation filter of a Burt Pyramid analyzer and/or synthesizer useful in implementing the present invention; and

FIG. **5** is a block diagram of a preferred embodiment of the coring means of FIG. **2**, which coring means is suitable for coring a video signal defining a scanned two-dimensional television image.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The distinctive feature of the present invention is that its spectrum analyzer and synthesizer each incorporates only filters having gradual rolloff filter characteristics, rather than "brickwall" filter characteristics. FIG. **1** illustrates the distinction between an idealized "brickwall" filter characteristic and a generalized gradual rolloff filter characteristic. As indicated by graph **100**, within a passband extending from a lower cutoff frequency f_L to an upper cutoff frequency f_h, a "brickwall" filter passes frequency components of a signal without attenuation, while all out-of-band frequency components of this signal below f_L or above f_h are completely attenuated. The center frequency f_c of the band is equal to the average of the respective cutoff frequencies f_h and f_L, while the bandwidth is equal to the difference between the respective cutoff frequencies f_h and f_L. If the filter is a bandpass filter, the value of the lower cutoff frequency f_L is greater than zero. However, if the filter is a low-pass filter, the value of the lower cutoff frequency f_L is zero.

In a spectrum analyzer for separating the frequency spectrum of an input signal into a plurality of contiguous subspectra signals, a "brickwall" filter characteristic completely prevents frequency components within one subspectrum from contaminating an adjacent subspectrum. However, the problem with a "brickwall" filter is that it rings when shock-excited by the energy

of an out-of-band high-frequency pulse. For example, consider a video signal representing a horizontally scanned image comprised of a bright narrow light stripe surrounded by a relatively dark, substantially large uniform background area. The relatively dark background will contain spatial frequencies that fall within a relatively low spatial frequency subspectra. However, when the horizontal scan passes across the edge of the narrow bright light vertical stripe, a short, high-amplitude pulse is generated in the video signal that shock-excites a low spatial frequency subspectrum "brick-wall" filter into ringing. This causes a high spatial frequency bright ringing artifact to be generated which is superimposed on the portion of the dark background immediately following the bright vertical stripe. Such an artifact is quite noticeable because, as mentioned earlier, the human visual system is quite sensitive to a high spatial frequency spurious component superimposed on a low spatial frequency background. The present inventors point out it is undesirable to remove noticeable noise present in the original input signal by a process which, in itself, adds noticeable artifacts to the displayed image.

A generalized gradual rolloff filter characteristic for a bandpass filter is shown in graph **102** that has a center frequency f_c. Since the rolloff is gradual, there are no distinct lower and upper cutoff frequencies f_L and f_h to define the bandwidth of the passband of the filter. Instead, the nominal lower and upper cutoff frequencies f_L and f_h are defined by those frequencies at which the filter attenuates an input signal by a preselected amount (e.g. the half-power points shown in FIG. **1**). The nominal bandwidth of the filter is then the difference between the nominal upper cutoff frequency f_h and the nominal lower cutoff frequency f_L. However, as indicated by the shaded regions **104** in FIG. **1**, a small amount of the energy in a given subspectrum band of a spectrum analyzer employing gradual rolloff filters will result in the contamination of adjacent subspectrum bands. This has a tendency to produce spurious aliasing spatial frequencies in an image-processing system employing sampled and subsampled signals. However, the image-processing system of the present invention, described in detail below, minimizes the effect of any aliasing.

In the case of a gradual rolloff bandpass filter, shown generally by graph **102** of FIG. **1**, rolloff usually occurs on both the higher and lower frequency sides of the center frequency f_c. In the case of a gradual rolloff low-pass filter, however, only the high frequency side of the center frequency f_c actually rolls off. The exact shape of the roll-off of any specific gradual rolloff filter characteristic is a matter of design. Design criteria suitable for gradual rolloff filters employed by the image-processing system of the present invention is discussed in more detail below.

FIG. **2** is a functional block diagram of an idealized embodiment of the present invention. A non-ringing, non-aliasing localized transform, octave-band spectrum analyzer **200** has an image-representing signal I supplied as an input thereto. In principle, input signal I can be a continuous analog signal, a sampled analog signal (such as is employed by CCD imagers and signal-translators) or a sampled digital signal (such as is derived from an analog-to-digital converter). In practice, however, image processing of the type being discussed is nearly always carried out on a sampled image-representing signal by a spectrum analyzer employing a digital com-

puter in non-real time or, alternatively, employing physical hardware that may operate either in real time or in non-real time. Therefore, for illustrative purposes, it is assumed that input signal I is a sampled signal, rather than a continuous signal.

As indicated in FIG. **2**, the image-representing signal I is defined in at least one dimension of the represented image by a spectrum of spatial frequencies within a range extending from a maximum frequency f_m to zero. In order that signal I contain no spatial frequencies higher than f_m, it is assumed to have been passed through a prefilter. For illustrative purposes, it will be assumed that input signal I is a temporal video signal derived from a conventionally scanned two-dimensional television image (although this is not essential). In any case, analyzer **200** separates the spatial frequency spectrum of input signal I into N (where N is any given integer) contiguous bandpass subspectra output signals $L_0 \ldots L_{N-1}$, and a remnant subspectrum output signal G_N. Bandpass subspectra output signals $L_0 \ldots L_{N-1}$ are arranged in descending spatial frequency order, starting from f_m, into respective nominal bandwidths of one octave within the range f_m to zero. Remnant subspectrum output signal G_0 contains all those spatial frequencies of the spectrum of input signal I which are below those contained in the (N−1) bandpass subspectrum (which is the lowest spatial frequency bandpass subspectrum). More specifically, as shown in FIG. **2**, octave I has a nominal bandwidth of $f_m/2$ and a center frequency of $3f_m/4$, octave **2** has a nominal bandwidth of $f_m/4$ and a center frequency of $3f_m/8$, and so forth.

Each of coring means **202-1** . . . **202-N** has a corresponding one of the subspectra output signals $L_0 \ldots L_{N-1}$ and G_N applied as an input thereto. Respective outputs $L_0 \ldots L_{N-1}$ and G_N from coring means **202-1** . . . **202-N** are applied to corresponding ones of non-ringing, non-aliasing filters **204-1** . . . **204-N** of spectrum synthesizer **206**. Spectrum synthesizer **206** also includes summer **208** for summing the respective outputs from filters **204-1** . . . **204-N** to derive a reconstructed output image-manifesting signal I_R.

Spectrum analyzer **200** performs a linear transformation on the image spatial frequency spectrum of the image-representing input signal I. Therefore, in the ideal case in which spectrum analyzer **200** provides a substantially non-ringing, non-aliasing localized transform, no significant amount of baseband spatial frequency will be present in any of the respective outputs from spectrum analyzer **200** which is not also present in the image spatial frequency spectrum of the input image-representing signal I. Thus, no significant amounts of spurious spatial frequency components are introduced by spectrum analyzer **200**. However, coring means **202-1** . . . **202-N**, which inherently operate in a non-linear manner, do introduce spurious spatial frequency components in each of the output signals $L'_0 \ldots L'_{N-1}$ and G'_N. These spurious spatial frequency components are comprised of harmonic components and intermodulation components of the subspectrum spatial frequencies applied as an input to each of coring means **202-1** . . . **202-N**. All harmonics of any spatial frequency within an octave-bandwidth subspectrum have spatial frequencies above that octave-bandwidth subspectrum. Also, those intermodulation components having a spatial frequency equal to the sum of different spatial frequencies within an octave-bandwidth subspectrum are situated above that octave-bandwidth subspectrum. Further, those intermodulation components having a

spatial frequency equal to the difference between different spatial frequencies within an octave-bandwidth subspectrum are situated below that octave-bandwidth subspectrum.

If the output from a coring means operating on an octave-bandwidth subspectrum input were applied to a bandpass filter exhibiting a "brickwall" characteristic (of the type shown in graph **100** of FIG. **1**), all the spurious spatial frequencies of the harmonic and intermodulation components generated by the coring means would be rejected by the filter. However, for the reasons discussed above, such a "brickwall" characteristic filter would tend to introduce shock-excited spurious spatial frequency ringing components. In order to avoid introduction of such spurious spatial frequency ringing components, such bandpass filter should have a gradual rolloff filter characteristic (such as shown in graph **102** of FIG. **1**) and a nominal bandwidth of an octave. In this latter case, a small amount of out-of-band harmonic and intermodulation spatial frequency components will not be completely rejected because of the presence of the out-of-band portions of the gradual rolloff filter characteristic (i.e., the shaded portions **104** shown in FIG. **1**). However, as discussed in more detail below, the amount of spurious spatial frequency components due to a gradual rolloff characteristic can be made insignificant (i.e. essentially unnoticeable in a displayed image) by proper filter design.

Each of filters **204-1** . . . **204**-(N−1) of spectrum synthesizer **206** may be bandpass filters or, alternatively, low-pass filters. In the case in which these filters are bandpass filters, each filter has a center frequency and a nominal bandwidth corresponding to the octave subspectrum with which it is associated. In the case in which these filters are low-pass filters, they have a nominal bandwidth from zero to a nominal upper cutoff frequency that is the same as that of a corresponding bandpass filter associated with the same octave subspectrum. Filter **204**-N associated with the remnant subspectrum, is a low-pass filter having a nominal upper cutoff frequency substantially equal to a lower cutoff frequency of the (N−1) octave subspectrum.

If low-pass (rather than bandpass) filters are employed for octave filters **204-1** . . . **204**-(N−1), the below-band difference (beat) spurious spatial frequency components of the coring process will not be rejected. However, such beat intermodulation signals tend to be low-level signals that are not easily noticed by the human visual system if present in a displayed image. In part this is because these lower spatial frequency beats are de-localized and randomly overlapping, and in part this is due to the masking effect of the relatively high-level signal content of most real world images in the lower spatial frequency portion of the image spatial frequency spectrum. Further, in practical systems, suitable non-ringing, non-aliasing gradual rolloff characteristics are more easily implemented for low-pass filters than for bandpass filters.

Although, in FIG. **2**, each and every one of the subspectra output signals from analyzer **200** has an individual coring means associated therewith, it is not essential to the present invention that this be the case. All that is required is that at least one of the subspectra output signals has a coring means individually associated therewith. However, if any of the coring means **202-2** . . . **202**-N, associated with subspectra composed of spatial frequencies below those of octave **1** (that is the highest spatial frequency subspectrum) is present, it must have a corresponding one of filters **204-2** . . . **204**-N of spectrum synthesizer **206** individually associated therewith in order to substantially remove therefrom at least the above-band spacious spatial frequency components due to the non-linear coring process. However, in the case of the octave **1** subspectrum, corresponding filter **204-1** of spectrum synthesizer **206** often is dispensed with. The reason for this is that most image displays are incapable of resolving spatial frequencies higher than the maximum spatial frequency f_m of the octave **1** subspectrum. Because any above-band spurious spatial frequencies present in the synthesized output signal I_R cannot be resolved in the image display, there is no need, in this particular case, to filter them out.

It is optional whether or not spectrum synthesizer **206** includes a non-ringing, non-aliasing filter individually associated with any one of the subspectra outputs in which coring is omitted. However, summer **208** sums all of the N bandpass and the remnant separate subspectra signals derived from spectrum analyzer **200**, regardless of whether coring is omitted and/or filtering is omitted from any of the subsepctra output signals from spectrum analyzer 200.

Reference is now made to FIG. *2a*, which illustrates a modified spectrum synthesizer **206*a*** which can be substituted for the spectrum synthesizer **206** of FIG. **2**. Spectrum synthesizer **206*a*** employs a plurality of low-pass filters **210-2** . . . **210**-N and partial summers **212-1** . . . **212**-(N−1). Low-pass filter **210-2** has a nominal upper cutoff frequency equal to one-half the maximum spatial frequency f_m of the image spatial frequency spectrum of the input image-manifesting signal I (that is the upper cutoff frequency of the octave **2** subspectrum). In a similar manner, each of the low-pass filters **210-3** . . . **210**-(N−1) has a nominal upper cutoff frequency equal to that of the octave subspectrum with which it is associated. Low-pass filter **210**-N has a nominal upper cutoff frequency equal to the nominal lower cutoff frequency of the (N−1) octave subspectrum.

In FIG. *2a*, the filters and partial summers in reverse ordinal order are intercoupled in cascade. The result is that the lowest spatial frequency subspectrum signal (cored remnant signal G'_N) is successively filtered, in turn, by each of the cascaded low-pass filters **210**-N . . . **210-2**. As indicated in FIG. *2a*, next-to-lowest spatial frequency subspectrum signal L'_{N-1} and the output of filter **210**-N are summed by partial summer **212**-(N−1), and then successively filtered, in turn, by each of the cascaded low-pass filters **210**-(N−1) . . . **210-2**. In a similar manner, each of the cored higher spatial frequency octave subspectra signals $L'_{(N-2)}$ . . . L'_2 is successively filtered, in turn, by all of the filters of spectrum synthesizer **206*a*** which are shown in FIG. *2a* above that cored subspectrum signal. Finally, the output from filter **210-2** is summed with the cored highest spatial frequency octave subspectrum L'_0 by partial summer **212-1** to derive a reconstructed output image-representing signal I_R. In FIG. *2a*, it is assumed that the image display cannot resolve spatial frequencies above the maximum spatial frequency f_m of the input image spectrum, so that it is not necessary to provide a low-pass filter for the output from partial summer **212-1**.

Based on the discussion of FIGS. **2** and *2a*, it is essential to the present invention that no output subspectrum signal from spectrum analyzer **200**, other than the remnant signal, have a nominal bandwidth of more than one octave. However, the principles of the present invention apply to analyzed bandpass subspectra signals each

having a spatial frequency bandwidth smaller than one octave.

The Burt Pyramid spectrum analyzer and the Burt Pyramid spectrum synthesizer, described in detail in the aforesaid co-pending Carlson et al. application, are particularly suitable for use in a practical implementation of spectrum analyzer **200** and spectrum synthesizer **206***a* of the present invention for at least two reasons. First, the Burt Pyramid permits filters with gradual rolloff characteristics, rather than "brickwall" characteristics, to be suitable for use in both its spectrum analyzer and spectrum synthesizer. Second, in its most preferred form, the Burt Pyramid spectrum analyzer generates nominal octave bandwidth bandpass subspectra output signals and a remnant subspectrum output signal.

The Burt Pyramid analyzer disclosed in the aforesaid co-pending Carlson et al. patent application operates on a sampled input signal designated G_0. In the following description of the Burt Pyramid, it is assumed that G_0, which corresponds with the image-representing input signal I of FIG. **2**, is in the form of a conventional video signal (e.g. an NTSC video signal) defining the spatial frequency spectrum of successively scanned two-dimensional television images, which video signal first has been prefiltered to remove any component thereof representing a spatial frequency higher than a given maximum spatial frequency f_m and then has been sampled at a sampling frequency of at least twice f_m.

The real-time Burt Pyramid analyzer disclosed in the aforesaid co-pending Carlson et al. patent application is shown in the FIG. **3***a* functional diagram. As indicated in FIG. **3***a*, the analyzer is comprised of a pipeline of generally similar sampled-signal translation stages **300-1**, **300-2** . . . **300**-N. Each of the respective stages operates at a sample frequency determined by the value of the digital clock CL_1, CL_2 . . . CL_N individually applied thereto. The value of the clock applied to any particular one of the stages is lower than the value of the clock applied to any stage that precedes it. In the case of the present invention, the value of each of the clocks of stages **300-2** . . . **300**-N is one-half of the clock of the immediately preceding stage.

As indicated in FIG. **3***a*, stage **300-1** is comprised of convolution filter and decimation means **302**, delay means **304**, subtraction means **306** and expansion and interpolation filter means **308**. An input stream of digital samples G_0, having a sample frequency equal to the value of clock CL_1 is applied through convolution filter and decimation means **302** to derive an output stream of digital samples G_1 at a sample frequency equal to the value of clock CL_2. The convolution filter has a low pass function that reduces the center frequency of each image dimension represented by G_1 to one-half of the center-frequency of the corresponding dimension represented by G_0. At the same time, the decimation reduces the sample density in each dimension by one-half.

The respective digital samples of G_0 are applied through delay means **304** as a first input to subtraction means **306**. At the same time, the reduced-density digital samples of G_1 are applied to expansion and interpolation filter **308**, which increases the sample density of the G_1 samples back to that of G_0. Then, the expanded density interpolated G_1 samples are applied as a second input to subtraction means **306**. The presence of delay means **304** ensures that each pair of samples of G_0 and G_1, which correspond with one another in spatial position, are applied to the first and second inputs of subtraction means **306** in time coincidence with one another. The output stream of successive samples L_0 from subtraction means **306** defines the highest spatial frequency in each dimension of the scanned image.

The structure of each of stages **300-2** . . . **300**-N is essentially the same as that of stage **300-1**. However, each of the higher ordinal numbered stages **300-2** . . . **300**-N operates on lower spatial frequency signals occurring at lower sample densities than its immediately preceding stage. More specifically, the output stream of successive samples L_1 represents the next-to-highest octave of spatial frequencies in each image dimension, etc., so that, as indicated in FIG. **3***a*, the Burt Pyramid analyzed signal is comprised of respective octave sample streams $L_0 \ldots L_{N-1}$ (derived respectively from the subtraction means of each of stages **300-1** . . . **300**-N) together with a low-frequency remnant signal G_N (derived from the output of the convolution filter and decimation means of stage **300**-N).

Referring to FIG. **3***b*, there is a Burt Pyramid synthesizer corresponding to synthesizer **206***a* of FIG. **2***a*, for deriving the reconstituted output signal I_R. This is accomplished by the use of appropriate delay means **310-0** . . . **310**-(N−1) operating on the cored sample streams $L'_0 \ldots L'_{N-1}$, together with expansion and interpolation filters **312-1** . . . **312**-N and summers **314-0** . . . **314**-(N−1). As indicated, the lowest density remnant sample stream G_N has its sampling density doubled in each of the image spatial dimensions represented thereby by expansion and interpolation filter **312**-N, and is then added to a delayed sample stream L_{N-1} by the summer **314**-(N−1). By iteration of this process—through successive synthesis stages, the reconstituted output signal I_R, defining the cored two-dimensional image at the highest sample density, is derived.

The respective convolution filters and interpolation filters employed by the Burt Pyramid are low-pass filters that must meet each of the following two constraints. First, each of these filters employs a symmetric kernel weighting function composed of at least three multiplier coefficients. Second, the multiplier coefficients of the kernel weighting function must provide equal contribution; that is, all nodes at a given level must contribute the same total weight to nodes at the next higher level. Practical provision for a substantially non-ringing, non-aliasing, localized transform filter characteristic, as required by the present invention, imposes additional constraints on the kernel weighting function employed by the convolution and interpolation low pass filters of a Burt Pyramid analyzer and synthesizer used for implementing the present invention. These additional constraints will now be considered.

Because each stage of the Burt Pyramid analyzer shown in FIG. **3***a* operates on a sampled input signal, the spatial frequency spectrum of such sampled input signal will not only include a baseband portion, but will include respective repeat portions consisting of both a lower and an upper sideband each modulating the fundamental of the sampling frequency and each of the harmonics of the sampling frequency. Further, in order to prevent aliasing, the sampling frequency should be at least twice the maximum frequency of the baseband spatial frequency spectrum of the sampled input signal to each stage of the Burt Pyramid analyzer.

By mathematical analysis, it can be shown that, at baseband, each of Burt Pyramid spectrum analyzer stages **300-1** . . . **300**-N approximates a non-ringing, non-aliasing localized transform device for deriving a corresponding octave-bandwidth one of Burt Pyramid

analyzed signals $L_0 \ldots L_{N-1}$, when each of the following listed relationships is true:

1. Over the spatial frequency range $O \leqq f \leqq f_h/4$ (where f_h is the nominal upper cutoff frequency of each octave subspectrum signal), the product of the respective normalized transmission characteristics of the convolution and interpolation filters of each stage is unity. Preferably, each of the convolution and interpolation filters of each stage, itself, has a transmission characteristic of unity over this range.
2. Over the spatial frequency range $f_h \leqq f \leqq 3f_h/4$, the product of the respective normalized transmission characteristics of the convolution and interpolation filters of each stage has a gradual rolloff. Preferably, each of the convolution and interpolation filters of each stage, itself, has a gradual rolloff over this range.
3. Over the spatial frequency range $3f_h/4 \leqq f \leqq f_h$, the product of the respective normalized transmission characteristics of the convolution and interpolation filters of each stage is zero. Preferably, each of the convolution and interpolation filters of each stage, itself, has a transmission characteristic of zero over this range.

Only the convolution filter of stage **300-N** of the Burt Pyramid analyzer is employed to generate the remnant subspectrum signal G_N. Therefore, in the case of stage **300-N**, the convolution filter thereof should substantially conform to each of criteria **1**, **2** and **3**, listed above. Also, each of the interpolation filters of the Burt Pyramid synthesizer shown in FIG. 3*b* should conform to each of these three criteria (where f_h, in the case of the synthesizer, is the upper cutoff frequency of the signal output of the summer immediately following each interpolation filter of FIG. 3*b*).

The design of practical convolution and interpolation filters must not only substantially conform to all three of the above-listed criteria, but also must conform to the constraints of symmetrical and equal-contribution kernel weighting functions, discussed above. Such a Burt Pyramid sampled-signal convolution or interpolation filter employing a kernel weighting function comprised of only three multiplier coefficients cannot meet either above-listed criterion 1 or criterion 3. For a sampling frequency just equal to twice the nominal upper cutoff frequency f_h of an octave (the minimum sampling frequency necessary to prevent aliasing), a five multiplier-coefficient kernel weighting function sampled-signal Burt-Pyramid convolution or interpolation filter can be designed which meets either of the above-listed criteria 1 and 2, but not both. To design a practical Burt-Pyramid convolution or interpolation filter which meets all of the above-listed three criteria requires at least a seven multiplier-coefficient kernel weighting function sampled-signal filter. More particularly, for the case in which the sampling frequency has its minimum substantially non-aliasing value of just twice the nominal upper cutoff frequency f_h of the filter input-signal spectrum, the FIG. **4** baseband filter characteristic (substantially meeting all of the above-listed three criteria) is defined by the seven multiplier-coefficient, symmetrical, equal contribution filter kernel weighting function shown in FIG. **4***a*, when the variable p has a value of minus (−)0.052.

For the case under discussion (in which the sampling frequency has its nominal minimum non-aliasing value), a seven multiplier-coefficient kernel weighting function provides a substantially localized transform, since it operates on a relatively localized image region. A nine multiplier-coefficient kernel weighting function (which is usually sufficiently small to still provide a substantially localized transform for its nominal minimum non-aliasing sampling frequency) may be desirable because it permits a greater fine-tuning capability than does a seven multiplier-coefficient kernel weighting function in defining the shape of the gradual rolloff portion of the baseband filter characteristic. However, for a nominal minimum non-aliasing sampling frequency, the filter transform tends to become more and more non-localized as the number of multiplier coefficients of the filter kernel weighting function increases beyond nine, and this is undesirable. On the other hand, if the filter input signal is oversampled (i.e. the sampling frequency is significantly greater than twice the nominal upper cutoff frequency f_h of the filter input signal spectrum) the number of multiplier coefficients in the kernel weighting function must be increased accordingly to provide the same filter characteristic with the same degree of localization. For instance, if the sampling frequency in FIGS. **4** and **4***a* were four time f_h, the kernel weighting function having the same envelope as the kernel weighting function of FIG. **4***a* would be comprised of thirteen to fifteen multiplier coefficients (that is, an interpolated-value multipler coefficient would be inserted between each pair of adjacent multiplier coefficients of FIG. **4***a*).

Because coring is a non-linear process and introduces artifacts, it is not desireable to core any more than is necessary to remove the noise that is actually present in the signal input to the coring means. Put another way, the coring threshold should be maintained at the lowest level sufficient to remove the amount of noise then currently present in the signal input to the coring means. FIG. **5** is a block diagram of a preferred embodiment of each of coring means **202-1** . . . **202-N** for use with a standard (e.g. NTSC) video signal representing a scanned two-dimensional television image. As is known in television, such as video signal includes successive interlaced scanned fields, with each scanning field being made up of an active field portion, during which image information is transmitted, and a vertical blanking portion, during which no image information is transmitted. The noise present during the vertical blanking portion of each successive field can be employed as a measure of the noise component during the active portion of the following field.

As shown in FIG. **5**, coring means **202-K** (where K corresponds with any ordinal one of coring means **202-1** . . . **202-N**) is comprised of switch **500** to which a control signal is applied for closing switch **500** only during the occurrence of the vertical blanking portion of each successive field. Therefore, switch **500** is maintained in its open condition during the entire active portion of each successive field. The L_{K-1} subspectrum output signal, associated with coring means **202-K** is applied as a signal input to both switch **500** and non-linear amplifier **502**. Thus, only the noise component of L_{K-1} is forwarded by closed switch **500** to rectifier **504** (since the signal during a vertical blanking portion consists solely of noise). The rectified noise component from rectifier **504** is applied to integrator **506**, which exhibits a time constant to sufficiently long to stretch the rectified noise component signal occurring during each vertical blanking portion of a field to entirely cover the immediately following active portion of the field. Therefore, integrator **506** generates a dc threshold sig-

nal having an adjustable magnitude ϵ_K for each active portion of a field that is proportional to the absolute level of the noise component (and is consequently directly related to the strength of the noise component) during the immediately preceding vertical blanking portion of a field. This adjustable threshold is applied as a control signal to non-linear amplifier **502**. In addition, the gain of a non-linear amplifier of each one of coring means **202-N** . . . **202-K** is individually adjusted by a gain adjust control so that the effect on overall signal gain of the different thresholds for each of coring means **202-1** . . . **202-N** is compensated for. More particularly, as the threshold magnitude ϵ_K becomes relatively larger, the relative power of the cored output signal L'_{K-1} from non-linear amplifier **502** becomes smaller compared to that of the L_{K-1} input signal thereto. The gain adjustment compensates for this fact so that the power contribution to the synthesizer output signal I_R signal from each separately cored subspectrum signal, such as the L'_{K-1} output from non-linear amplifier **502**, remains substantially the same as that of the corresponding L_{K-1} subspectrum signal to the input signal I to the spectrum analyzer.

Non-linear amplifier **502** operates by amplifying only that portion of the L_{K-1} input signal thereto which has an absolute level exceeding the current magnitude of the adjustable threshold. Thus, even when the absolute level of the input signal exceeds the current magnitude of the adjustable threshold, only the clipped portion of the input signal that exceeds the current magnitude is passed by non-linear amplifier **502** and contributes to the coring means L'_{K-1} output signal power. An alternative technique would be to compare the absolute level of the input signal with the magnitude of the adjustable threshold and, if the absolute level of the input signal exceeds the magnitude of the threshold, all of the input signal would be passed to the L'_{K-1} output; otherwise, none of the input signal would be passed. This alternative technique has the advantage that appreciably more of the input signal power is retained in the output signal power. However, in wide-band coring schemes, a disadvantage of this alternative technique is that it tends to produce a high spatial frequency artifact known as "sparkle" in the displayed image derived from the output of such a coring means. However, an image processing system using narrow-band coring in accordance with the principles of the present invention the filtering after coring suppresses "sparkle", making this alternative technique more practical.

What is claimed is:

1. An image-processing system comprising:

a substantially non-ringing, non-aliasing, localized transform spectrum analyzer responsive to an input image-representing signal defined in at least one dimension of the represented image by a spectrum of spatial frequencies within a range extending downward from a maximum frequency f_m to zero, said analyzer separating said input-signal spectrum in descending spatial frequency order starting from f_m into a group of one or more contiguous bandpass subspectra output signals each of which subspectrum has a nominal bandwidth no greater than one octave within said range, and into a remnant subspectrum output signal contining all those spatial frequencies of said input-signal spectrum which are below those contained in the lowest spatial frequency bandpass subspectrum output-signal;

means for coring at least one of said bandpass subspectra output signals and remnant subspectrum output signal, thereby introducing spurious out-of-band spatial frequency components into each cored subspectrum output signal; and

a spectrum synthesizer coupler to said analyzer through said coring means and responsive to all of said subspectra signals from said analyzer being applied thereto for deriving an output image-representing signal;

wherein said synthesizer is comprised of substantially non-ringing, non-aliasing filter means individually associated with the subspectrum of at least each cored signal that is lower than the highest spatial frequency bandpass subspectrum output signal, for substantially removing at least those spurious frequency components therefrom which are above-band with regard to that subspectrum, and means for summing all said subspectra signals, including both any that has been cored and/or filtered and any that has been neither cored nor filtered, thereby to derive said output image representing signal;

whereby any noise component originally present in the spectrum of said input image-representing signal has been reduced in the spectrum of said output image-representing signal without introducing any signifficant amount of aliasing or other spurious spatial frequency component in the spectrum of said output image-representing signal.

2. The system defined in claim **1**, wherein:

said output image-representing signal is to be employed to display an image on a display device having a resolution capability insufficient to noticeably display any spatial frequency higher than f_m; and

said highest spatial frequency octave output signal from said spectrum is coupled through said coring means to said summing means without having any of said synthesizer filter means individually associated therewith.

3. The system defined in claim **1**, wherein each of said synthesizer filter means is comprised of a low-pass filter having a gradual rolloff about a nominal cutoff frequency equal to the upper spatial frequency of the subspectrum with which that filter means is individually associated.

4. The system defined in claim **3**, wherein said synthesizer comprises:

at least two of said low-pass filters that are coupled in cascade through a summer, a first of said filters being individually associated with a relatively lower one of said subspectra and a second of said filters being individually associated with a relatively higher one of said subspectra;

means for applying said relatively lower one of said subspectra signals as an input to said first of said low-pass filters;

means for applying the output of said first of said low-pass filters as a first input to said summer;

means for applying said relatively higher one of said subspectra signals as a second input to said summer; and

means for applying the output of said summer as an input to said second of said low-pass filters;

whereby said lower one of said subspectra signals is filtered by both said first and second of said cascaded low-pass filters.

5. The system defined in claim 4, wherein both said lower and higher ones of said subspectra signals are cored subspectra signals.

6. The system defined in claim 5, wherein said lower and higher ones of said subspectra are contiguous subspectra.

7. The image-processing system defined in claim 1, wherein:

said input image-representing signal is a video signal representing an image that has been scanned in at least said one dimension; said video signal contains no temporal frequency corresponding to an image spatial frequency greater than f_m, and said video signal is sampled at a temporal sampling frequency corresponding to at least twice f_m;

said spectrum analyzer is a Burt Pyramid spectrum analyzer including one stage for deriving the highest one of said subspectra output signals therefrom, said one stage inlcuding (1) convolution filter-decimation means responsive to said sampled video signal for deriving a first filtered output signal therefrom at one-half the sample frequency of said video signal, (2) expander-interpolation means having said first filtered output signal applied as an input thereto for deriving a second filtered output signal therefrom at the same sample frequency as said video signal, and (3) means for subtracting the level value of each sample of said second filtered output signal from the level value of the corresponding sample of said video signal to thereby derive said highest one of said subspectra output signals as the output from said subtraction means; and

each of the convolution filter and interpolation filter of said one stage exhibits a filter spatial frequency characteristic in accordance with a symmetrical, equal-contribution kernel weighting function that includes at least seven multiplier-coefficients having respective values such that the product of the respective filter spatial frequency characteristics of said convolution and interpolation filters is a given spatial frequency characteristic (a) which is substantially unity over a spatial frequency range extending from zero to $f_m/4$(b) which has a gradual rolloff over a spatial frequency range extending from $f_m/4$ to $3f_m/4$, and (c) which is substantially zero over a spatial frequency range extending from $3f_m/4$ to f_m.

8. The image-processing system defined in claim 7, in which each of said convolution and interpolation filters exhibits said given spatial frequency characteristic.

9. The image-processing system defined in claim 8, wherein:

said Burt Pyramid analyzer includes N stages where N is a plural integer and said one stage is the first ordinal one of said N stages, for respectively deriving each of said bandpass subspectra output signals, and at least each of said second to (N−1)th stage includes (1) a convolution filter decimation means responsive to the first filtered output signal from the convolution filter decimation means of the immediately preceding stage for deriving a first filtered output therefrom at one-half the sample frequency of that of the first filtered output signal from the convolution filter-decimation means of the immediately preceding stage, (2) expander-interpolation filter means having said first filtered output of that stage applied as an input thereto for deriving a second filtered output signal therefrom at the sampling frequency of the first filtered output signal of the immediately preceding stage, and (3) means for subtracting the level value of each sample of said second filtered output signal of a stage from the corresponding sample of the first filtered output signal of the immediately preceding stage to thereby derive an octave-bandpass subspectra output signal corresponding to that stage; and

each of the convolution filter and interpolation filter of each of said second to (N−1)th stage exhibits a filter spatial frequency characteristic in accordance with a symmetrical, equal contribution kernel weighting function that includes at least seven multiplier-coefficients having respective values such that the respective spatial frequency characteristic of said convolution filter and interpolation filter of a stage (a) is substantially unity over a range extending from zero to $f_m/4$, where f_m is the nominal upper frequency of the spatial frequency spectrum of the first filtered output signal of the immediately preceding stage, (b) has a gradual rolloff over a spatial frequency range extending from $f_m/4$ to $3f_m/4$, and (c) is substantially zero over a spatial frequency range extending from $3f_m/4$ to f_m.

10. The image-processing system defined in claim 9, wherein:

wherein all of the second to Nth stages include the elements (1) (2) and (3) defined in claim 9 and have the spatial frequency characteristics (a), (b) and (c) defined in claim 9, and

said remnant subspectra output signal of said analyzer is the first filtered output signal of said Nth stage.

11. The image-processing system defined in claim 10, wherein said synthesizer is a Burt Pyramid synthesizer including:

an ordinal set of N expander-interpolation filter means and summers that individually correspond with each of the N stages of said Burt Pyramid analyzer, said expander-interpolation filter means and summers being intercoupled in cascade in reverse order with the output of each expander-interpolation filter means being applied as a first input to a summer and the output of that summer being applied as an input to the immediately preceding ordinal one of said expander-interpolation filter means in said set, said remnant subspectrum signal being applied as an input to the Nth expander-interpolation filter means of said set, the bandpass subspectrum signal associated with each of said N stages of said analyzer being applied as a second input to the corresponding summer of said set, whereby the output of the summer of said set corresponding to the first stage of said analyzer constitutes said output image-representing signal; and

wherein each of the interpolation filters exhibits a filter spatial frequency characteristic in accordance with a symmetrical, equal contribution kernel weighting function that includes at least seven multiplier-coefficients having respective values such that the respective spatial frequency characteristic of said interpolation filter of a stage (a) is substantially unity over a range extending from zero to $f_m/4$, where f_m is the nominal upper frequency of the spatial frequency spectrum of the first filtered output signal of the immediately pre-

ceding stage, (b) has a gradual rolloff over a spatial frequency range extending from $f_m/4$ to $3f_m/4$, and (c) is substantially zero over a spatial frequency range extending from $3f_m/4$ to f_m.

12. The image-processing system defined in claim **11**, wherein said input-image-representing signal is a video signal representing a two-dimensional image that has been scanned in both of said two dimensions.

13. The image-processing system defined in claim **1**, wherein said input-image-representing signal is a video signal representing a two-dimensional image that has been scanned in both of said two dimensions.

14. The image-processing system defined in claim **13**, wherein:

said video signal is a television raster-scanned video signal comprised of successively-occurring scanning fields, each of said scanning fields including a blanking portion followed by an active video portion; and

each of said coring means includes first means comprised of switch means and time-constant means for deriving an adjustable threshold control signal having a magnitude during the active video portion of each scanning field which is a direct function of the noise level of the subspectrum output signal applied as an input to that coring means solely during the blanking portion of that scanning field, and second means controlled by said threshold control signal for deriving an output from that coring means only if the level of the input signal to that coring means during each scanning field exceeds the magnitude of said threshold control signal during that scanning field.

15. An image processing system for processing an input spectrum-analyzed image-representing signal, wherein said image-representing signal that has been spectrum-analyzed defines, in at least one dimension of the represented image spectrum, spatial frequencies within a range extending from a maximum frequency f_m down to zero, and wherein said spectrum-analyzed image-representing signal, starting with f_m, is comprised, in descending spatial frequency order, of a group of one or more separate contiguous bandpass subspectra signals, each of which has a nominal bandwith no greater than one octave within said range, and a remnant subspectrum signal containing all those spatial frequencies of said image-representing signal spectrum which are below those contained in the lowest spatial frequency bandpass spectrum signal; said system including:

means for coring at least one of said bandpass subspectra signals, thereby introducing spurious out-of-band spatial frequency components into each cored subspectrum signal; and

a spectrum synthesizer coupled to said coring means and having all analyzed subspectra signals, including both those that have been cored and those that have not been cored, applied thereto for deriving an output image-representing signal;

wherein said synthesizer is comprised of substantially non-ringing, non-aliasing filter means individually associated with the subspectrum of at least each cored signal that is lower than the highest spatial frequency bandpass subspectrum output signal, for substantially removing at least those spurious frequency components therefrom which are above-band, and means for summing all said subspectra signals, including both any that has been cored and/or filtered and any that has been neither cored nor filtered, thereby to derive said output image-representing signal;

whereby any noise component originally present in said spectrum analyzed image-representing signal has been reduced in the spectrum of said output image-representing signal without introducing any significant amount of aliasing or other spurious spatial frequency component in the spectrum of said output image-representing signal.

16. The system defined in claim **15**, wherein:

said output image-representing signal is to be employed to display an image on a display device having a resolution capability insufficient to noticeably display any spatial frequency higher than f_m; and

said highest spatial frequency octave output signal from said spectrum is coupled through said coring means to said summing means without having any of said synthesizer filter means individually associated therewith.

17. The system defined in claim **15**, wherein each of said synthesizer filter means is comprised of a low-pass filter having a gradual rolloff about a nominal cutoff frequency equal to the upper spatial frequency of the subspectrum with which that filter means is individually associated.

18. The system defined in claim **17**, wherein said synthesizer comprises:

at least two of said low-pass filters that are coupled in cascade through a summer, a first of said filters being individually associated with a relatively lower one of said subspectra and a second of said filters being individually associated with a relatively higher one of said subspectra;

means for applying said relatively lower one of said subspectra signals as an input to said first of said low-pass filters;

means for applying the output of said first of said low-pass filters as a first input to said summer;

means for applying said relatively higher one of said subspectra signals as a second input to said summer; and

means for applying the output of said summer as an input to said second of said low-pass filters;

whereby said lower one of said subspectra signals is filtered by both said first and second of said cascaded low-pass filters.

19. The system defined in claim **18**, wherein both said lower and higher ones of said subspectra signals are cored subspectra signals.

20. The system defined in claim **19**, wherein said lower and higher ones of said subspectra are contiguous subspectra.

21. The image-processing system defined in claim **15**, wherein:

said image-representing signal which has been spectrum analyzed is a video signal representing an image that has been scanned in at least said one dimension; said video signal contains no temporal frequency corresponding to an image spatial frequency greater than f_m, and said video signal is sampled at a temporal sampling frequency corresponding to at least twice f_m;

said group of bandpass subspectra signal is comprised of N bandpass subspectra signals, where N is a plural integer;

said synthesizer is a Burt Pyramid synthesizer that includes an ordinal set of N expander-interpolation filter means and summers, said expander-interpolation filter means and summers being intercoupled in cascade in reverse order with the output of each expander-interpolation filter means being applied as a first input to a summer and the output of that summer being applied as an input to the immediately preceding ordinal one of said expander-interpolation filter means in said set, said remnant subspectrum signal being applied as an input to the Nth expander-interpolation filter means of said set, the bandpass subspectrum signal associated with each of said N bandpass subspectra signals being applied as a second input to the corresponding summer of said set, whereby the output of the summer of said set corresponding to the first stage of said analyzer constitutes said output image-representing signal; and

wherein each of the interpolation filters exhibits a filter spatial frequency characteristic in accordance with a symmetrical, equal contribution kernel weighting function that includes at least seven multiplier-coefficients having respective values such that the respective spatial frequency characteristic of said interpolation filter of a stage (a) is substantially unity over a range extending from zero to $f_m/4$, where f_m is the nominal upper frequency of the spatial frequency spectrum of the first filtered output signal of the immediately preceding stage, (b) has a gradual rolloff over a spatial frequency range extending from $f_m/4$ to $3f_m/4$, and

(c) is substantially zero over a spatial frequency range extending from $3f_m/4$ to f_m.

22. The image-processing system defined in claim **21**, wherein said input-image-representing signal is a video signal representing a two-dimensional image that has been scanned in both of said two dimensions.

23. The image-processing system defined in claim **15**, wherein said input-image-representing signal is a video signal representing a two-dimensional image that has been scanned in both of said two dimensions.

24. The image-processing system defined in claim **23**, wherein:

said video signal is a television raster-scanned video signal comprised of successively-occurring scanning fields, each of said scanning fields including a blanking portion followed by an active video portion; and

each of said coring means includes first means comprised of switch means and time-constant means for deriving an adjustable threshold control signal having a magnitude during the active video portion of each scanning field which is a direct function of the noise level of the subspectrum output signal applied as an input to that coring means solely during the blanking portion of that scanning field, and second means controlled by said threshold control signal for deriving an output from that coring means only if the level of the input signal to that coring means during each scanning field exceeds the magnitude of said threshold control signal during that scanning field.

* * * * *

United States Patent [19]
Bayer

[11] Patent Number: 4,549,212
[45] Date of Patent: Oct. 22, 1985

[54] IMAGE PROCESSING METHOD USING A COLLAPSED WALSH-HADAMARD TRANSFORM

[75] Inventor: Bryce E. Bayer, Rochester, N.Y.

[73] Assignee: Eastman Kodak Company, Rochester, N.Y.

[21] Appl. No.: 522,278

[22] Filed: Aug. 11, 1983

[51] Int. Cl.[4] H04N 5/21; H04N 5/14

[52] U.S. Cl. 358/167; 358/284; 364/727

[58] Field of Search 358/166, 167, 284, 133, 358/113, 138, 260; 382/43; 364/727

[56] References Cited

U.S. PATENT DOCUMENTS

4,055,756 10/1977 Jolivet et al. 364/725
4,179,709 12/1979 Workman 358/133
4,242,705 12/1980 Ebihara 358/167
4,442,454 4/1984 Powell 358/167

OTHER PUBLICATIONS

"Hadamard Transform Image Coding," by W. K. Pratt, H. C. Andrews, and J. Kane, *Proceedings of the IEEE,* 57, 1, Jan. 1969, pp. 58–68.

"Digital Technique of Reducing Television Noise," by J. P. Rossi, *Journal of the Society of Motion Picture and Television Engineers,* Mar. 1978, pp. 134–140.

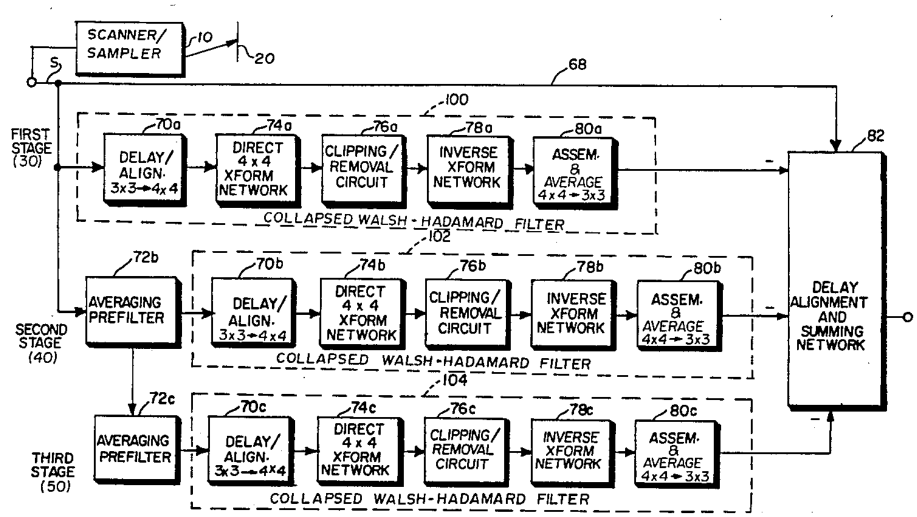
"Mathematical Analysis: On a generalization of the Hermite polynomials," by M. Krawtchouk, Academy of Sciences (Fr.), reported from the meeting of Sep. 23, 1929, pp. 620–622 (original in French).

Primary Examiner—John C. Martin
Assistant Examiner—E. Anne Toth
Attorney, Agent, or Firm—David M. Woods

[57] ABSTRACT

An improved image processing method uses a modified Walsh-Hadamard transform to remove noise and preserve image structure in a sampled image. Image signals representative of the light value of elements of the image are grouped into signal arrays corresponding to blocks of image elements. These signals are mapped into larger signal arrays such that one or more image signals appear two or more times in each larger array. The larger arrays are transformed by Walsh-Hadamard combinations characteristic of the larger array into sets of coefficient signals. Noise is reduced by modifying—i.e., coring or clipping—and inverting selected coefficient signals so as to recover processed signals—less noise—representative of each smaller signal array. The results exhibit acceptable rendition of low contrast detail while at the same time reducing certain processing artifacts characteristic of the unimproved Walsh-Hadamard block transform.

12 Claims, 14 Drawing Figures



$$\begin{matrix} 1 & 1 \\ 1 & 1 \end{matrix} \qquad \begin{matrix} 1 & -1 \\ 1 & -1 \end{matrix}$$

$$\begin{matrix} 1 & 1 \\ -1 & -1 \end{matrix} \qquad \begin{matrix} 1 & -1 \\ -1 & 1 \end{matrix}$$

FIG. 1

$$\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix} \qquad \begin{bmatrix} 1 & 0 & 2 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 4 & 0 & 2 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 2 & 0 & 1 \end{bmatrix}$$

A B

FIG. 5

A. FIRST STAGE

```
x x x
x x x
x x x
```

B. SECOND STAGE

```
x - x - x -
- - - - - -
x - x - x -
- - - - - -
x - x - x -
- - - - - -
```

C. THIRD STAGE

```
x - - - x - - - x - - -
- - - - - - - - - - - -
- - - - - - - - - - - -
- - - - - - - - - - - -
x - - - x - - - x - - -
- - - - - - - - - - - -
- - - - - - - - - - - -
- - - - - - - - - - - -
x - - - x - - - x - - -
- - - - - - - - - - - -
- - - - - - - - - - - -
- - - - - - - - - - - -
```

FIG. 6

$$\begin{matrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{matrix} \quad \begin{matrix} 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 \end{matrix} \quad \begin{matrix} 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 \end{matrix} \quad \begin{matrix} 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 \end{matrix}$$

$$\begin{matrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 \end{matrix} \quad \begin{matrix} 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 \\ -1 & -1 & 1 & 1 \end{matrix} \quad \begin{matrix} 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & -1 \\ -1 & 1 & 1 & -1 \end{matrix} \quad \begin{matrix} 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 \\ -1 & 1 & -1 & 1 \\ -1 & 1 & -1 & 1 \end{matrix}$$

$$\begin{matrix} 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 \\ 1 & 1 & 1 & 1 \end{matrix} \quad \begin{matrix} 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 \\ -1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 \end{matrix} \quad \begin{matrix} 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & -1 \\ -1 & 1 & 1 & -1 \\ 1 & -1 & -1 & 1 \end{matrix} \quad \begin{matrix} 1 & -1 & 1 & -1 \\ -1 & 1 & -1 & 1 \\ -1 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{matrix}$$

$$\begin{matrix} 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 \\ 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 \end{matrix} \quad \begin{matrix} 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 \end{matrix} \quad \begin{matrix} 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & -1 \\ 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & -1 \end{matrix} \quad \begin{matrix} 1 & -1 & 1 & -1 \\ -1 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 \\ -1 & 1 & -1 & 1 \end{matrix}$$

FIG. 2

92

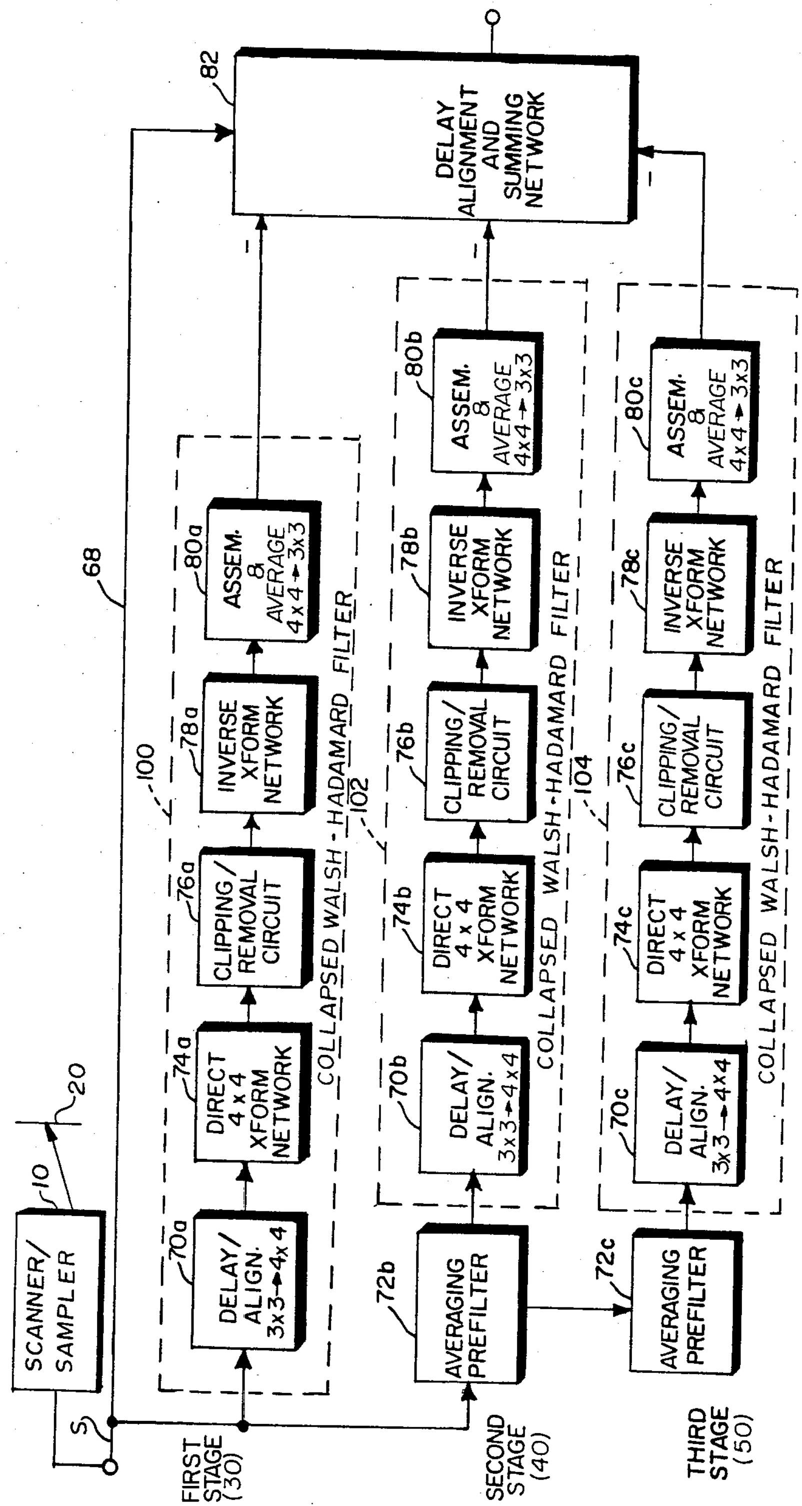
$$\begin{matrix}1&2&1\\2&4&2\\1&2&1\end{matrix}\qquad\begin{matrix}1&0&-1\\2&0&-2\\1&0&-1\end{matrix}\qquad\begin{matrix}1&-2&1\\2&-4&2\\1&-2&1\end{matrix}\qquad\begin{matrix}1&0&-1\\2&0&-2\\1&0&-1\end{matrix}$$

$$\begin{matrix}1&2&1\\0&0&0\\-1&-2&-1\end{matrix}\qquad\begin{matrix}1&0&-1\\0&0&0\\-1&0&1\end{matrix}\qquad\begin{matrix}1&-2&1\\0&0&0\\-1&2&-1\end{matrix}\qquad\begin{matrix}1&0&-1\\0&0&0\\-1&0&1\end{matrix}$$

$$\begin{matrix}1&2&1\\-2&-4&-2\\1&2&1\end{matrix}\qquad\begin{matrix}1&0&-1\\-2&0&2\\1&0&-1\end{matrix}\qquad\begin{matrix}1&-2&1\\-2&4&-2\\1&-2&1\end{matrix}\qquad\begin{matrix}1&0&-1\\-2&0&2\\1&0&-1\end{matrix}$$

$$\begin{matrix}1&2&1\\0&0&0\\-1&-2&-1\end{matrix}\qquad\begin{matrix}1&0&-1\\0&0&0\\-1&0&1\end{matrix}\qquad\begin{matrix}1&-2&1\\0&0&0\\-1&2&-1\end{matrix}\qquad\begin{matrix}1&0&-1\\0&0&0\\-1&0&1\end{matrix}$$

FIG. 3



DELAY ALIGNMENT AND SUMMING NETWORK
82
68
SCANNER/ SAMPLER
10
20
S
DELAY/ ALIGN. 3x3→4x4
DIRECT 4x4 XFORM NETWORK
CLIPPING/ REMOVAL CIRCUIT
INVERSE XFORM NETWORK
ASSEM. & AVERAGE 4x4→3x3
70a
74a
76a
78a
80a
100
COLLAPSED WALSH - HADAMARD FILTER
102
70b
74b
76b
78b
80b
104
72b
72c
70c
74c
76c
78c
80c
AVERAGING PREFILTER
FIRST STAGE (30)
SECOND STAGE (40)
THIRD STAGE (50)

FIG. 4

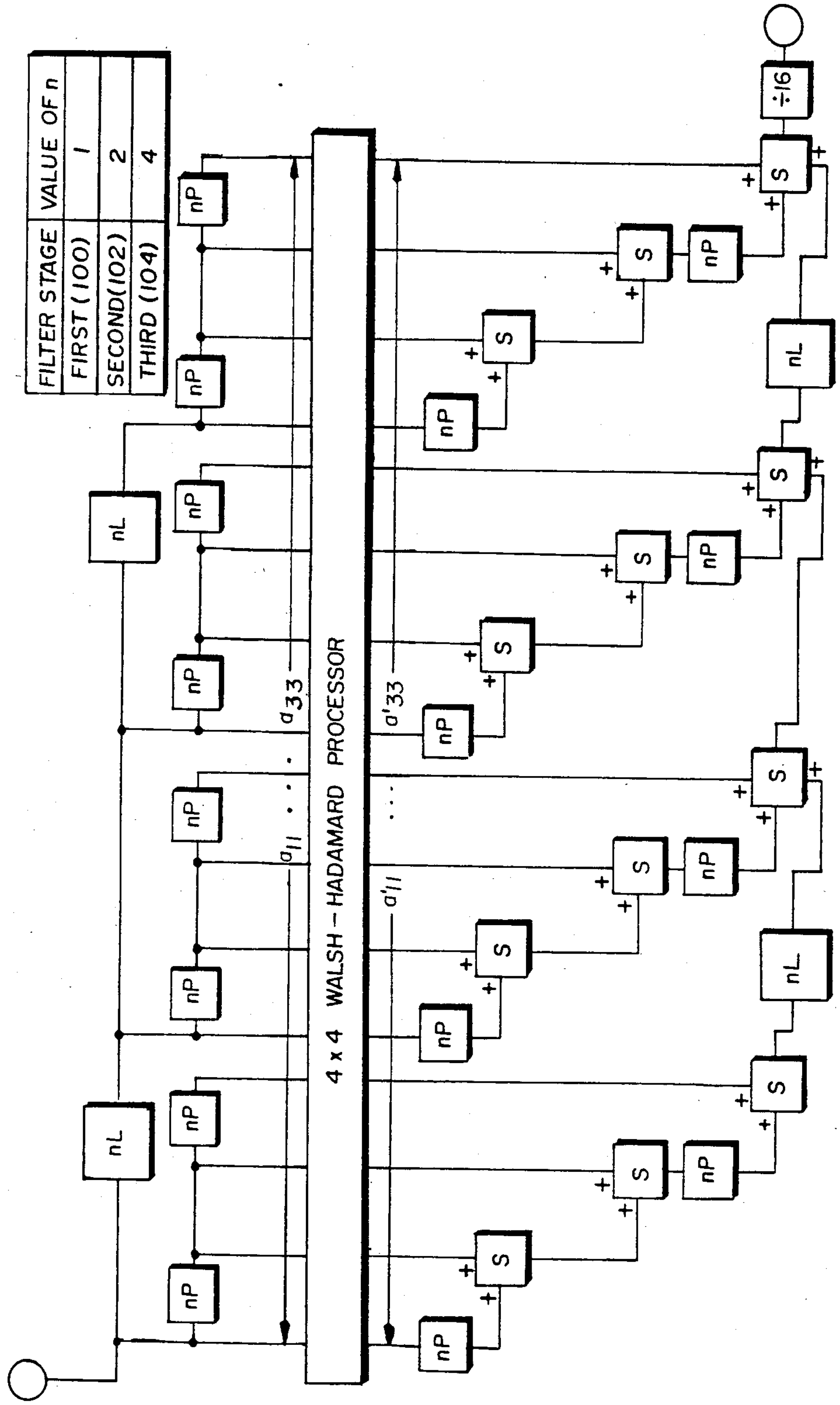

FILTER STAGE | VALUE OF n
FIRST (100) | 1
SECOND (102) | 2
THIRD (104) | 4
4 x 4 WALSH – HADAMARD PROCESSOR
nP
nL
S
÷16
a_{11}
a_{33}
a'_{11}
a'_{33}

FIG. 7

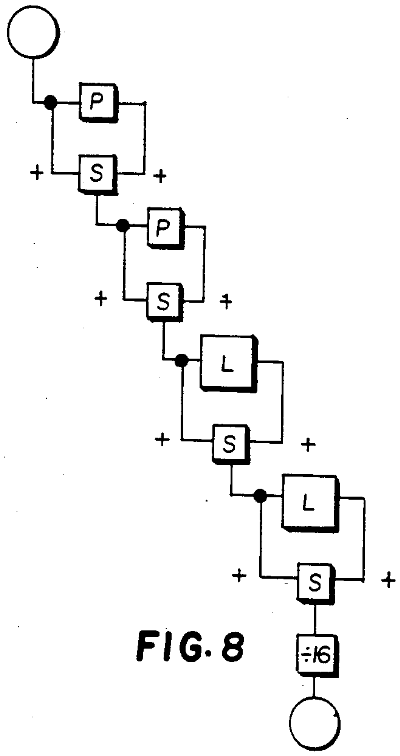


FIG. 8

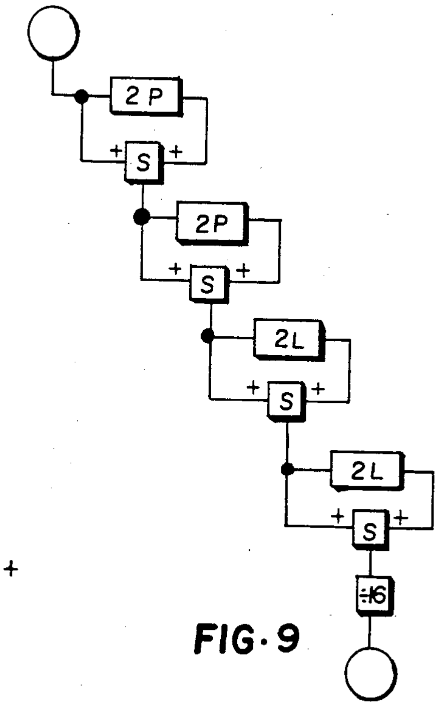


FIG. 9

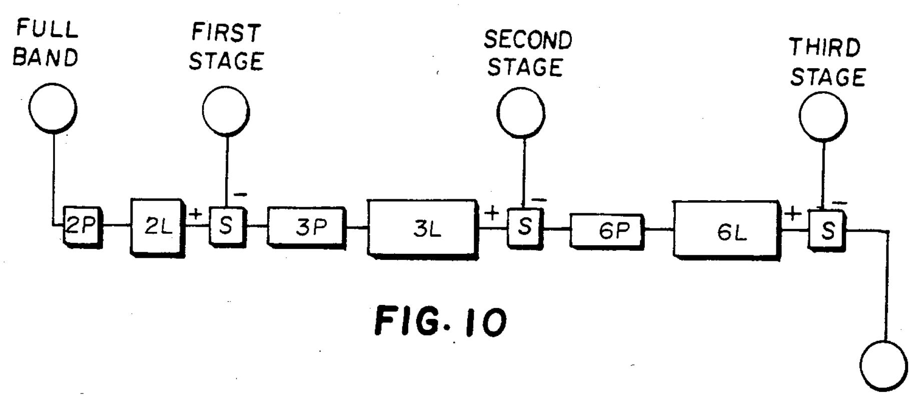
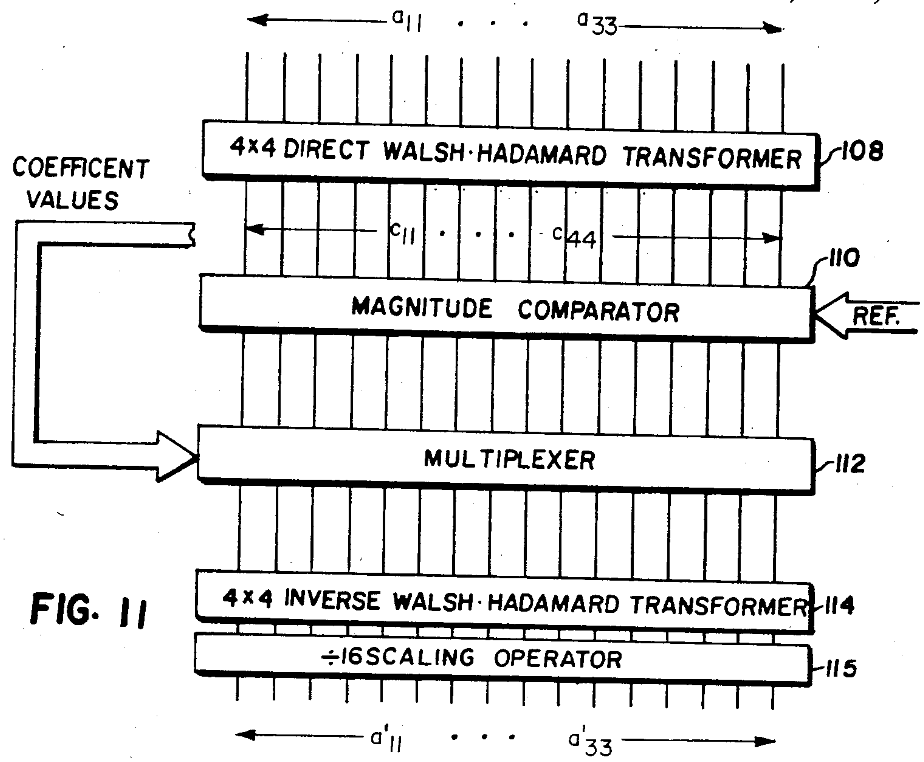
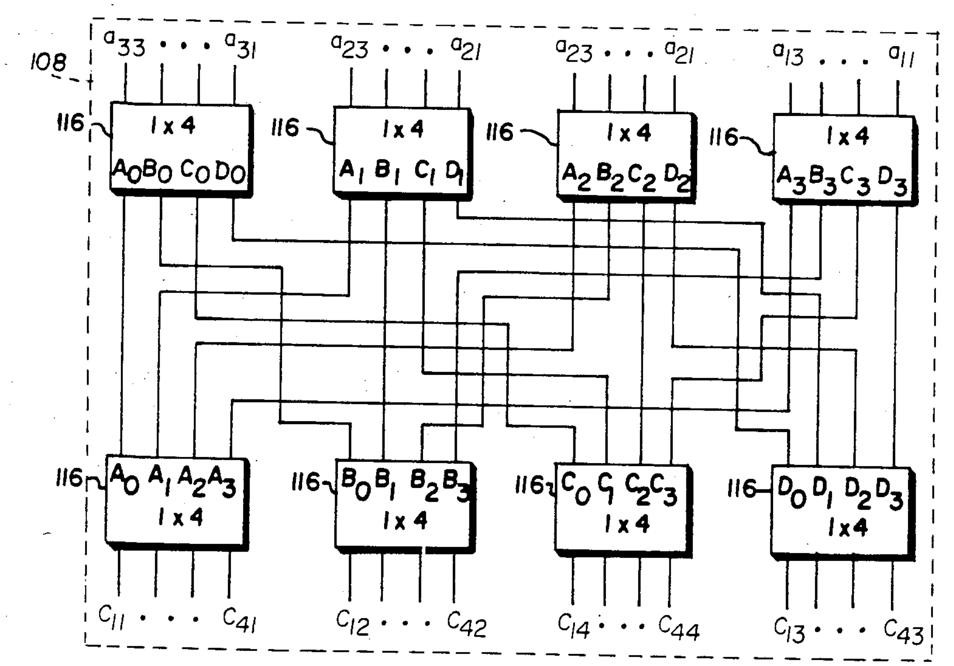


FIG. 10



a_{11} . . . a_{33}
4x4 DIRECT WALSH·HADAMARD TRANSFORMER
108
COEFFICENT VALUES
c_{11} . . . c_{44}
110
MAGNITUDE COMPARATOR
REF.
MULTIPLEXER
112
4x4 INVERSE WALSH·HADAMARD TRANSFORMER
114
÷16SCALING OPERATOR
115
a'_{11} . . . a'_{33}

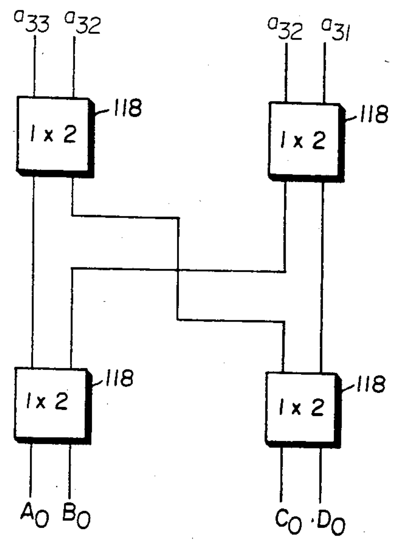
FIG. 11



108
a_{33} . . . a_{31}
a_{23} . . . a_{21}
a_{23} . . . a_{21}
a_{13} . . . a_{11}
116
1x4
$A_0 B_0 C_0 D_0$
$A_1 B_1 C_1 D_1$
$A_2 B_2 C_2 D_2$
$A_3 B_3 C_3 D_3$
$A_0 A_1 A_2 A_3$
$B_0 B_1 B_2 B_3$
$C_0 C_1 C_2 C_3$
$D_0 D_1 D_2 D_3$
C_{11} . . . C_{41}
C_{12} . . . C_{42}
C_{14} . . . C_{44}
C_{13} . . . C_{43}

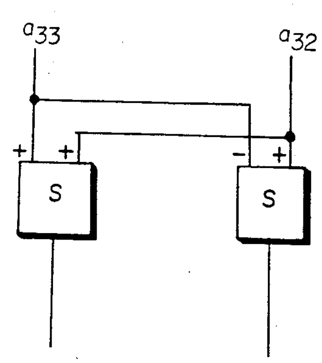
FIG. 12

FIG. 13



a_{33} a_{32}
a_{32} a_{31}
118
1 x 2
118
1 x 2
118
1 x 2
118
1 x 2
A_0 B_0
C_0 D_0

FIG. 14



a_{33}
a_{32}
+ +
− +
S
S

IMAGE PROCESSING METHOD USING A COLLAPSED WALSH-HADAMARD TRANSFORM

BACKGOUND OF THE INVENTION

1. Field of the Invention

The invention relates to image processing methods for reducing noise in a sampled image. More specifically, the invention pertains to an image processing method which uses the Walsh-Hadamard transform to remove noise and preserve image structure.

2. Description Relative to the Prior Art

Image processing methods using the Walsh-Hadamard transform are well known to those of ordinary skill in the image processing art. For that reason, the description relative to the prior art and relative to an embodiment of the invention will include only such detail regarding the Walsh-Hadamard transform as is useful and sufficient to describe the improved use of the transformation in accordance with the invention. For further information regarding the Walsh-Hadamard transform, reference may be made to *Digital Image Processing* by W. K. Pratt (John Wiley & Sons, New York, 1978) and especially chapter 10 thereof, "Two-Dimensional Unitary Transforms" and the bibliographic references cited therein (especially "Hadamard Transform Image Coding," by W. K. Pratt, H. C. Andrews, and J. Kane, *Proc. IEEE,* 57, 1, January 1969, 58–68).

In the interest of processing efficiency, the Walsh-Hadamard transform may be configured to operate on relatively small arrays of image signals generated from blocks of image elements—a type of transform processing herein referred to as block processing. In addition, the overall process may be partitioned into a number of stages. Both of these features are found in commonly assigned, copending patent application Ser. No. 441,826, now U.S. Pat. No. 4,442,454 "Image Processing Method Using a Block Overlap Transformation Procedure," filed Nov. 15, 1982), which describes a transform processing method that operates in a hierarchy of stages, each stage employing a Walsh-Hadamard block transform operating on an array of image signals derived from a preceding stage. In particular, one embodiment described in Ser. No. 441,826, now U.S. Pat. No. 4,442,454 shows a 2 by 2 Walsh-Hadamard transform operating on a 2 by 2 array of image signals.

Processed images resulting from an image processing method using such a 2 by 2 Walsh-Hadamard transform often display artifacts introduced by the processing method itself. These artifacts may be suppressed by using a Walsh-Hadamard transform operating on a larger array of image signals, such as a 4 by 4 array generated from a 4 by 4 block of image elements. Such a method—employing a 4 by 4 array—is described in commonly assigned, copending patent application Ser. No. 522,284, entitled "Transform Processing Method For Reducing Noise In An Image," and filed on even date herewith. However, while suppressing these artifacts, certain image features, such as low-contrast edges, rendered well by the smaller 2 by 2 transform, are relatively degraded by use of the larger 4 by 4 transform. Before describing my solution to this type of problem, it is helpful to review certain known aspects of the Walsh-Hadamard transformation, in both 2 by 2 and 4 by 4 configurations.

Starting with a 2 by 2 Walsh-Hadamard transform, let a 2 by 2 block of image elements be represented as a block of four image elements A_{ij}, as follows.

$$\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}$$

The corresponding image signals are generated from the light values of these elements (light value, as used herein shall mean any image-related characteristic—e.g., lightness, brightness, density, hue and the like—that can be expressed in a form suitable for image processing). The image signals are represented as an array of four image signals a_{ij}, as follows.

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

An array of four transform coefficient signals c_{ij},

$$\begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix}$$

are generated from the image signals in four linear arithmetic combinations characteristic of the 2 by 2 Walsh-Hadamard transform, as follows.

$$c_{11}=a_{11}+a_{12}+a_{21}+a_{22}$$

$$c_{12}=a_{11}-a_{12}+a_{21}-a_{22}$$

$$c_{21}=a_{11}+a_{12}-a_{21}-a_{22}$$

$$c_{22}=a_{11}-a_{12}-a_{21}+a_{22}$$

Each coefficient signal is a particular linear combination of the light values from image elements within the block. Each combination (except coefficient signal c_{11}) represents a particular component of the image structure—such as detail—and tends to vanish in the absence of that particular kind of structure.

By inspecting these linear arithmetic combinations, it can be seen that each coefficient signal corresponds to a particular summation of all the image signals in the block, allowing some image signals to be positive (multiplied by $+1$) and others to be negative (multiplied by -1). In this connection, FIG. **1** is an abbreviated way of listing the arithmetic operations necessary to generate these linear combinations. The ±1 multipliers for each linear combination mentioned above are grouped into an array of four multipliers, each multiplier corresponding in position to the image element, and signal, it operates upon. Four such arrays are provided corresponding to the four linear arithmetic combinations mentioned above for generating the four coefficient signals. The array composed of four $+1$ multipliers generates an average coefficient signal (the c_{11} coefficient signal) over the 2 by 2 area. The other three arrays generate coefficient signals in response to differences in light value between image elements—differences that represent image gradients.

Noise is reduced in the processed image by modifying one or more of the coefficient signals. The noise reduction process typically involves either coring or clipping. Coring is a non-linear noise reduction process that re-

moves coefficient signal ernegy—presumably noise—near the average coefficient signal axis and less than a threshold; signal energy in the remaining coefficient signals is then combined with low-pass signal energy represented by the average coefficient signal. The effect of this combination occurs during the inverse transformation of the coefficient signals, which will be described further in the upcoming description. (See "Digital Techniques of Reducing Television Noise," by J. P. Rossi, *Journal of the Society of Motion Picture and Television Engineers,* Mar. 1978, pp. 134–140.) Clipping is a complementary process that removes coefficient signal energy—presumably image detail—that is above a threshold; the noise signal remaining after inverse transformation is then subtracted from a full-band image signal.

Processed image signals (representing the original image signals less noise) are then recovered by inverse transforming the coefficient signals, including the one or more that were modified (and, in the case of clipping, subtracting the inverted signals from the full-band image signal). Since the Walsh-Hadamard transform is exactly invertible, the four processed image signals a'_{ij} are recovered by employing the four combinations represented in FIG. 1, but now with the coefficient signals in place of the unprocessed image signals (and a proportionality factor of $\frac{1}{4}$), as follows.

$$a'_{11}=\tfrac{1}{4}(c_{11}+c_{12}+c_{21}+c_{22})$$

$$a'_{12}=\tfrac{1}{4}(c_{11}-c_{12}+c_{21}-c_{22})$$

$$a'_{21}=\tfrac{1}{4}(c_{11}+c_{12}-c_{21}-c_{22})$$

$$a'_{22}=\tfrac{1}{4}(c_{11}-c_{12}-c_{21}+c_{22})$$

The 2 by 2 Walsh-Hadamard transform performs particularly well in reconstructing small, local image gradients such as found in low-contrast detail, like edges. However, any coefficient signal sensitive to a block-wide local gradient is similarly sensitive to segments of more extended gradients. For example, a coefficient signal generated from a block covering only a few image elements not only responds to the abrupt change of a small, local gradient, e.g., a low contrast edge, but also responds to a gradual change in a smooth, extended image gradient—such as is frequently found within smooth areas of scene objects. An artifact arises when a threshold set up to distinguish low contrast detail in a local block is "falsely" triggered by a smooth, extended gradient. Then, an abrupt discontinuity—much like an "edge"—will undesirably appear in the processed image at the point where the threshold is crossed and the corresponding linear combination is undesirably modified. Hence the name "false edge" artifact is given to such unwanted transitions arising from use of a method such as described in Ser. No. 441,826, now U.S. Pat. No. 4,442,454.

The heretofore-cited patent application Ser. No. 522,284, describes a transform processing method that suppresses the "false edge" artifact by modifying—i.e., coring or clipping—and inverting only selected transform coefficient signals from each array of signals c_{ij}. In order to do this with the Walsh-Hadamard transform, it is necessary to transform a larger number of image signals than are provided by a 2 by 2 block of image elements. The size suggested in Ser. No. 522,284 is one including signals from a 4 by 4 block of image elements.

Apart from involving a larger block of image elements and therefore involving a greater number of linear combinations, the operation of the 4 by 4 Walsh-Hadamard transform is analogous to that of the 2 by 2 Walsh-Hadamard transform. As an example, let a 4 by 4 block of image elements be represented as a block of sixteen image elements A_{ij},

$$\begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} \\ A_{21} & A_{22} & A_{23} & A_{24} \\ A_{31} & A_{32} & A_{33} & A_{34} \\ A_{41} & A_{42} & A_{43} & A_{44} \end{bmatrix}$$

and the image signals obtained from the corresponding light values as an array of sixteen image signals a_{ij}, as follows.

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}$$

An array of sixteen coefficient signals c_{ij},

$$\begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix}$$

is generated from the image signals in sixteen linear arithmetic combinations characteristic of the 4 by 4 Walsh-Hadamard transform, as follows (in part).

$$\begin{aligned} c_{11} &= a_{11} + a_{12} + a_{13} + a_{14} + a_{21} + a_{22} + a_{23} + a_{24} + \\ &\quad a_{31} + a_{32} + a_{33} + a_{34} + a_{41} + a_{42} + a_{43} + a_{44} \\ c_{12} &= a_{11} + a_{12} - a_{13} - a_{14} + a_{21} + a_{22} - a_{23} - a_{24} + \\ &\quad a_{31} + a_{32} - a_{33} - a_{34} + a_{41} + a_{42} - a_{43} - a_{44} \\ c_{13} &= a_{11} - a_{12} - a_{13} + a_{14} + a_{21} - a_{22} - a_{23} + a_{24} + \\ &\quad a_{31} - a_{32} - a_{33} + a_{34} + a_{41} - a_{42} - a_{43} + a_{44} \\ &\ \ \vdots \\ c_{44} &= a_{11} - a_{12} + a_{13} - a_{14} - a_{21} + a_{22} - a_{23} + a_{24} + \\ &\quad a_{31} - a_{32} + a_{33} - a_{34} - a_{41} + a_{42} - a_{43} + a_{44} \end{aligned} \tag{1}$$

FIG. 2 is a list of the sixteen arrays of ± 1 multipliers used in these sixteen arithmetic combinations for generating the corresponding sixteen coefficient signals c_{ij}. (It will be evident from FIG. 2 how to form the arithmetic combinations not shown above.) Apart from the average coefficient signal c_{11}, each coefficient signal is generated from differences in light value between image elements within the 4 by 4 block.

When the transform coefficient signals from the preceding 4 by 4 Walsh-Hadamard transform are processed in accordance with the heretofore-cited Ser. No. 522,284—that is, by modifying and inverting all but selected coefficient signals—the "false edge" artifact in the processed image is reduced. However, low-contrast detail in the processed image now suffers in comparison to the output from a transformation method based on use of the 2 by 2 Walsh-Hadamard transform, such as described in the heretofore cited Ser. No. 441,826, now U.S. Pat. No. 4,442,454. The choice of the transform

block size involves a trade-off between suppression of artifact and rendition of certain types of image structure, especially low contrast detail. From an aesthetic viewpoint, such artifacts detract from the overall visual appeal of images processed by such methods. On the other hand, the preservation of low-contrast detail in the processed image is desirable for aesthetic reasons. Whichever Walsh-Hadamard transform is chosen, the resulting processed image has aspects that are aesthetically unappealing. My invention provides more appealing results by striking a better balance between artifact and image structure.

SUMMARY OF THE INVENTION

I have found that the Walsh-Hadamard transform can be used to better advantage in block processing if the transform generates its characteristic linear combinations from an unconventional ordering of the image signals available to the transform. More specifically, the array of image signals obtained from a specific block, e.g., 3 by 3, of image elements are mapped into a larger array of image signals, e.g., 4 by 4. The larger array, including some image signals that appear more than once, is then transformed in accordance with the characteristic Walsh-Hadamard linear combinations appropriate for the larger array. In effect, the Walsh-Hadamard transformation method is collapsed upon a smaller block of image elements than is usual for the given size of transform. By completing the coefficient modification and inverse transforming with respect to the larger signal array, a better compromise is struck between the removal of "false edge" artifacts and the preservation of low-contrast detail.

The image processing method in accordance with the invention is an improvement upon prior image processing methods using the Walsh-Hadamard transformation. Image signals representative of the light value of elements of the image are grouped into arrays of signals prior to being transformed. The signals comprising these arrays are fewer than the number of signals ordinarily required by the particular size of Walsh-Hadamard transform in use. The improvement comprises mapping these fewer signals into yet larger signal arrays such that one or more image signals appear two or more times in the larger array. Then the larger number of signals comprising these larger arrays are transformed in accordance with the Walsh-Hadamard linear combinations appropriate for the larger array.

More specifically, the invention provides an improved method of transform processing of an image for both reducing noise and preserving image structure, particularly low contrast detail, such as edges. The coefficient signals resulting from transformation of the above-mentioned larger arrays represent combinations of image signals sensitive to a smoothed light value and to differences in light value among image elements. One or more of the coefficient signals are modified—as by coring or clipping—in order to reduce noise in the processed image, thereby preserving the residual image structure. Finally, the processed image having reduced noise is generated from these coefficient signals, some of which may have been modified in the preceding steps. In a specific embodiment, a 3 by 3 array of image signals is mapped into a 4 by 4 array such that the middle column and middle row of the smaller array are each duplicated in the larger array. The signals constituting the larger array are then transformed in accordance with

the Walsh-Hadamard combinations appropriate for a 4 by 4 array of signals.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with reference to the figures, wherein:

FIGS. **1** and **2** are tabular listings of the arithmetic combinations for generating the coefficient signals of a 2 by 2 and 4 by 4 Walsh-Hadamard transform, respectively;

FIG. **3** is a tabular listing of the arithmetic combinations for generating the coefficient signals characteristic of a 4 by 4 Walsh-Hadamard transform but "collapsed" upon a 3 by 3 field of image elements in accordance with the invention;

FIG. **4** is a block diagram of an image processing method in accordance with the invention;

FIGS. **5A** and **5B** are diagrams of the weighting arrays used for the prefilters of FIG. **4**;

FIGS. **6A**, **6B** and **6C** are diagrams illustrating the particular image signals selected for transformation at each stage of the method in accordance with the embodiment of FIG. **4**;

FIG. **7** is a generalized circuit diagram for implementing the first, second and third stage filters of FIG. **4**;

FIGS. **8** and **9** are circuit diagrams of the pair of averaging prefilters used in FIG. **4**;

FIG. **10** is a circuit diagram of the delay, alignment and summing network utilized in FIG. **4** to receive the full-band signal and the signal output from the first, second and third stage filters;

FIG. **11** is a circuit diagram of the Walsh-Hadamard processor incorporated in FIG. **7**;

FIG. **12** is a circuit diagram of a configuration of 1 by 4 arithmetic networks for implementing the direct and inverse transformers of FIG. **11**;

FIG. **13** is a circuit diagram of one of the 1 by 4 arithmetic networks incorporated in FIG. **12**; and

FIG. **14** is a circuit diagram of the summing components comprising each of the 1 by 2 arithmetic networks incorporated in FIG. **13**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The input signal in the following description is generated by the scanning and sampling of an original image. For purposes of describing the preferred embodiment the input signal is assumed to be generated from an image such as a negative or positive photographic transparency. It is further understood that such a signal may represent a variety of spatial components of the image, including an average light value level, fine detail such as fine edges, lines and textures; intermediate detail such as broader edges and small features; and coarse detail such as shaded modeling and other gradually varying features. (Modeling as here used refers to the rendition of smoothly varying features or details.) In addition, the signal includes a noise component affecting most of the spatial components to some degree. With a photographic transparency, much of such noise originates with the random distribution of the light-absorbing particles that form the basis of this image-recording system. While the invention will be described in connection with sampled data from a photographic transparency, it should be understood that the input signal can represent other information or data, such as would be derived from directly scanning an object, from a

composite video signal, or from image information in optical/electrical/magnetic storage. In such cases the noise originates in other characteristics of the signal generating system.

The invention will be described in accordance with a modification applied to a 4 by 4 Walsh-Hadamard transformation. Ordinarily, in taking a 4 by 4 transform of the image signals, the signal values involved in the transformation include samples taken from 4 elements of 4 lines of the original image, for a total of 16 signals from 16 samples. I have recognized that the techniques of direct and inverse Walsh-Hadamard transformation are still useful and valid if the signal values are accumulated and ordered in a different pattern.

More specifically, the sixteen signal values for the transformation are taken from the nine elements of a 3 by 3 block instead of the sixteen elements of a 4 by 4 block. That is, from the 3 by 3 block of image elements

$$\begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \tag{2}$$

a 3 by 3 array of image signals a_{ij},

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \tag{3}$$

is generated from the light values of the image elements.

These nine image signals $a_{11} \ldots a_{33}$ are mapped into a 4 by 4 array of image signals suitable for transformation, as follows.

$$\begin{bmatrix} (a_{11}) & (a_{12}) & (a_{12}) & (a_{13}) \\ (a_{21}) & (a_{22}) & (a_{22}) & (a_{23}) \\ (a_{21}) & (a_{22}) & (a_{22}) & (a_{23}) \\ (a_{31}) & (a_{32}) & (a_{32}) & (a_{33}) \end{bmatrix} \tag{4}$$

This is done by using image signals a_{11}, a_{13}, a_{31}, and a_{33} once; a_{12}, a_{21}, a_{23} and a_{32} twice; and a_{22} four times. An array of sixteen coefficient signals c_{ij},

$$\begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \tag{5}$$

is generated from the 4 by 4 array (4) of image signals in sixteen arithmetic combinations identical to those used [combinations (1)] for the 4 by 4 Walsh-Hadamard transform, excepting that certain of the image signals appear more than once in a given linear combination, as follows (in part).

$$\begin{aligned} c_{11} &= a_{11} + a_{12} + a_{12} + a_{13} + a_{21} + a_{22} + a_{22} + a_{23} + a_{21} + a_{22} + a_{22} + a_{23} + a_{31} + a_{32} + a_{32} + a_{33} \\ c_{12} &= a_{11} + a_{12} - a_{12} - a_{13} + a_{21} + a_{22} - a_{22} - a_{23} + a_{21} + a_{22} - a_{22} - a_{23} + a_{31} + a_{32} - a_{32} - a_{33} \\ c_{13} &= a_{11} - a_{12} - a_{12} + a_{13} + a_{21} - a_{22} - a_{22} + a_{23} + a_{21} - a_{22} - a_{22} + a_{23} + a_{31} - a_{32} - a_{32} + a_{33} \end{aligned} \tag{6}$$

-continued

$$\begin{aligned} &\vdots \\ c_{44} &= a_{11} - a_{12} + a_{12} - a_{13} - a_{21} + a_{22} - a_{22} + a_{23} + a_{21} - a_{22} + a_{22} - a_{23} - a_{31} + a_{32} - a_{32} + a_{33} \end{aligned}$$

Because of the duplication among image signals, combinations (6) reduce to (in part)

$$\begin{aligned} c_{11} &= a_{11} + 2a_{12} + a_{13} + 2a_{21} + 4a_{22} + 2a_{23} + a_{31} + 2a_{32} + a_{33} \\ c_{12} &= a_{11} - a_{13} + 2a_{21} - 2a_{23} + a_{31} - a_{33} \\ c_{13} &= a_{11} - 2a_{12} + a_{13} + 2a_{21} - 4a_{22} + 2a_{23} + a_{31} - 2a_{32} + a_{33} \\ &\vdots \\ c_{44} &= a_{11} - a_{13} - a_{31} + a_{33} \end{aligned} \tag{7}$$

FIG. 3 is a list of the sixteen arrays of multipliers (ranging from 0 to ±4) used in these sixteen arithmetic combinations for generating the corresponding sixteen coefficient signals c_{ij}. (As with the 4 by 4 Walsh-Hadamard transform, it is evident from FIG. 3 how to construct the linear combinations not shown above). The list of arrays in FIG. 3 can also be derived by inspecting FIG. 2 and combining like signals. In other words, by applying the same weight of ±1 to each signal value as shown in the arithmetic combinations of FIG. 2 and combining the weights for the elements used more than once, the sixteen combinations illustrated in FIG. 2 are condensed into the sixteen "collapsed" arithmetic combinations of FIG. 3. When incorporating these modifications, the Walsh-Hadamard transform will be hereinafter referred to as a "collapsed" Walsh-Hadamard transform since the characteristic linear combinations are "collapsed" upon a smaller field of image elements than is conventional in the prior art.

An image processing method incorporating the "collapsed" Walsh-Hadamard transform is implemented as shown in block form in FIG. 4. This method is generally of the type described in the aforementioned patent application Ser. No. 522,284. Parts of the method especially relating to the "collapsed" transformation are shown in accordance with the present invention. Conventional scanning and sampling apparatus **10** generates a stream of image signals by scanning a photographic negative **20**. Each signal relates to the light value of a respective element of an original image on the negative **20**. This signal stream, hereinafter called signal stream S, is processed through three stages. Each stage conveys signals sensitive to particular spatial components of the image: a first stage **30** conveys fine detail signals, a second stage **40** conveys intermediate detail signals and a third stage **50** conveys coarse detail signals. Noise signals, due to photographic grain, are distributed across all stages. The spatial scale of the noise signals in each stage corresponds to the spatial scale of the corresponding detail.

The "collapsed" 4 by 4 Walsh-Hadamard transform is used in each of the three stages shown in FIG. 4. Since each stage processes differently scaled detail and the same number of transform coefficient signals are available in each stage, the image signals generated for each stage after the first should be filtered or processed versions of either the original image signals or those signals processed in some preceding stage. For that purpose, suitably low-pass prefiltered image signals related to the

average light value of areas of the original image are provided in the second and third stages by use of averaging prefilters **72***b* and **72***c*. In the averaging prefilter **72***b* each image signal of the original image is replaced by a weighted average over a neighborhood of the original image signal in accordance with the weighting pattern of FIG. **5**A. In the averaging prefilter **72***c*, each of the once-averaged image signals is replaced by a weighted average over the larger neighborhood of once-averaged signals as indicated by the pattern of FIG. **5**B (in each case, the signal being replaced corresponds to the center weight of 4).

Although sixteen image signals are being transformed at one time in each stage, the sampling pattern of the image signals forming each 3 by 3 signal array processed by the "collapsed" Walsh-Hadamard transform, i.e., whether the signals comprising each array are adjacent or separated by "intervening" image signals, will depend on which stage is involved. FIG. **6** illustrates the pattern of particular image signals selected for the "collapsed" Walsh-Hadamard transformation at each stage. The letter x represents the image signals (including averaged image signals in the case of the second or third stage) selected at a particular moment to form the 3 by 3 signal arrays at each stage, while the dashes represent image signals (or averaged image signals) that do not provide inputs to the respective pattern at that moment.

In each stage, the continuous stream of such signal arrays effects a shifting of block boundary locations between successive blocks so as to cause block/block overlap. If the block/block overlap amounts to a shift of a single image element from the previous block, the selection of the array (3) of nine image signals for transformation at each stage means that each image signal in each stage contributes to the transformation of nine arrays (3) of image signals. (More information regarding a block overlap transformation procedure is found in copending Ser. No. 441,826, now U.S. Pat. No. 4,442,454.) However, since each image signal in any stage after the first is a filtered version of some preceding image signal, the nine image signals selected for transformation in such stages already include contributions from neighboring image signals due to the filtering process.

Referring again to FIG. **4**, the stream of image signals S is directly presented to a delay and alignment network **70***a* in the first stage and to the averaging prefilter **72***b* in the second stage; from the second stage the once-averaged image signals are presented to the averaging prefilter **72***c*. In addition, the stream of signals S bypass all stages on a line **68**. In the first stage **30**, the delay and alignment network **70***a* presents an array of image signals to a transform network **74***a* for effecting the "collapsed" Walsh-Hadamard transformation. The stream of once-averaged image signals from the prefilter **72***b* is applied to a delay and alignment network **70***b* in the second stage **40**, which presents an array of once-averaged image signals to a transform network **74***b* for effecting the "collapsed" Walsh-Hadamard transformation. The stream of twice-averaged image signals from the prefilter **72***c* is applied to a third delay and alignment network **70***c*, which presents an array of twice-averaged image signals to a transform network **74***c* for effecting the "collapsed" Walsh-Hadamard transformation in the third stage **50**.

Each delay and alignment network **70***a*, **70***b* and **70***c* is so configured as to map the array (3) of particular image

signals that are selected (relative to the image signal locations x of FIG. **6**) into the larger signal array (4) for the 4 by 4 "collapsed" Walsh-Hadamard transformation at each stage. That is, in the first stage **30** the 4 by 4 "collapsed" Walsh-Hadamard transform operates on sixteen image signals (some being the same) assembled from nine image signals from the incoming signal stream S. In the second stage **40** the 4 by 4 "collapsed" Walsh-Hadamard transform operates on sixteen image signals assembled from nine image signals taken from the next adJacent image signals of next adjacent rows of the once-averaged image signals presented by one alignment of the incoming stream of signals. In the third stage **50**, the 4 by 4 "collapsed" Walsh-Hadamard transform operates on sixteen image signals assembled from nine image signals taken from fourth adjacent image signals of fourth adjacent rows of the twice-averaged image signals presented by one alignment of the incoming stream of signals. In the next alignment of the incoming stream of image signals, new sets of nine image signals are presented to the delay and alignment stages, which present sixteen image signals to the respective transform networks. Every image signal therefore enters into nine image signal arrays in each stage (assuming one image element displacement between overlapped blocks). As a result of the second and third stages of processing averaged image signals, a large number of elements of the original image influence the reconstruction of each image element in the processed image.

Each transform network **74***a*, **74***b* and **74***c* transforms the image signals by a set of linear combinations (characteristic of the 4 by 4 Walsh-Hadamard transform) into a corresponding set of coefficient signals representative of a smoothed light value and differences in light value between image elements. (Smoothed light value is meant to include average, weighted average or other kinds of mean light values). The application of the sixteen arithmetic combinations defined by the arrays of FIG. **3** represents this process for the "collapsed" by 4 by 4 Walsh-Hadamard transform. These arithmetic combinations generate the 4 by 4 array (5) of coefficient signals c_{ij}. Sets of these coefficient signals are presented to respective clipping/removal circuits **76***a*, **76***b* and **76***c*, each of which have clipping levels chosen according to the expected noise levels (that is, noise as expressed in the transform coefficient signals conveyed through each of the stages). This being a clipping type of noise reduction process, coefficient signals less than the clipping levels—representing most of the noise—are passed unaffected to inverse transform networks **78***a*, **78***b* and **78***c*; coefficient signals greater than the clipping levels—representing most of the image information—are set to zero.

The results of the inverse transformation in the inverse transform networks **78***a*, **78***b* and **78***c* constitute arrays of processed signal components a'_{ij} corresponding to the image signal locations x shown in FIGS. **6**A, **6**B and **6**C respectively. These processed signal components are presented to respective assembly/averaging networks **80***a*, **80***b* and **80***c* in which the nine signal components (due to block/block overlap in each stage) pertaining to each image element are assembled by properly arranged delay elements and averaged together. The averaged, processed image signals (now predominantly noise) from each stage are then presented to the delay, alignment and summing network **82**, which provides delays to compensate for the delays

incorporated in the respective stages, aligns the processed image signals and subtracts these signals (which are predominantly noise signals) produced by all three stages from the unmodified full-band image signal presented on the line **68**.

In accordance with the teaching of the heretofore cited patent application Ser. No. 522,284, the coefficient signals c_{11}, c_{12}, c_{21} and c_{22} resulting from the four arithmetic operations outlined in broken line **92** (FIG. **3**) are set aside and not used during inversion. By regenerating the image signals from the signals resulting from the remaining twelve coefficient operations (which were clipped in the circuits **76***a*, **76***b* and **76***c* and inverted in the networks **78***a*, **78***b* and **78***c*), the objectionable artifact of "false edges" is reduced. By using the "collapsed" Walsh-Hadamard transform on a 3 by 3 block of image elements, local low contrast detail—such as low contrast edges—is better preserved than if the Walsh-Hadamard transform was used in conjunction with a 4 by 4 block of image elements. Consequently, a better balance is struck between artifact and image structure than is known to the prior art.

An image processing method employing a "collapsed" Walsh-Hadamard transform according to the present invention may be implemented by application of conventional digital hardware or by suitable programming of a digital computer. Such digital circuit design or software programming is conventional and within the capability of one of ordinary skill in these arts, given the preceding descriptions of the method in accordance with the invention. One implementation in conventional digital hardware is described in relation to FIGS. **7**–**14**. In this connection, portions of the block diagram of FIG. **4** constituting the respective filter stages are enclosed in broken lines. Henceforth, the box **100** will be referred to as the first stage "collapsed" 4 by 4 Walsh-Hadamard filter, the box **102** as the second stage "collapsed" 4 by 4 Walsh-Hadamard filter, and the box **104** as the third stage "collapsed" 4 by 4 Walsh-Hadamard filter. FIG. **7** illustrates a hardware implementation of the respective "collapsed" Walsh-Hadamard filter stages—with the assignment of n indicating which stage the hardware will implement. Regarding other portions of FIG. **4**, the averaging prefilters **72***b* and **72***c* are provided by the delay and summing elements shown in FIGS. **8** and **9**, respectively. The delay, alignment and summing network **82** is provided by the delay and summing elements connecting the configuration of inputs shown in FIG. **10**.

A number of similar components appear throughout the diagrams of FIGS. **7**–**14**, as follows. Line and element delay units are specified by boxes that are labeled with an "L" or "P" respectively. Where appropriate, a multiple of "L" or "P" is specified in a single box to indicate a corresponding multiple unit delay. (In FIG. **7**, the variable n signifies the multiplier for the delay. For the first stage, n=1; the second stage, n=2; and the third stage, n=4.) Summing points are specified by boxes that are labeled with an "S" and the prescribed signs of the inputs are specified by "+" or "−". Scaling operations are specified by boxes that are labeled with the division symbol "÷" followed by the particular divisor (i.e., scaling factor) employed in a specific operation. Moreover, the components for implementing the circuits described by FIGS. **7**–**14** are commonly obtained through ordinary supply sources. The choice of particular device types is well within the capability of those of ordinary skill in the electronics arts. Further

device specification is believed unnecessary for practice of the method in accordance with the invention.

Referring concurrently to FIG. **4** and FIGS. **7**–**14**, the stream of input image signals are presented simultaneously to the first stage filter **100** (FIG. **7**, n=1) and to the second stage averaging prefilter **72***b* (FIG. **8**). The structure of delay, summing, and averaging units illustrated in FIG. **8** implements the averaging pattern of FIG. **5**A. The resultant average is delivered to the second stage "collapsed" Walsh-Hadamard filter **102** (FIG. **7**, n=2) and to the third stage averaging prefilter **72***c* (FIG. **9**). The structure of delay, summing, and averaging units illustrated in FIG. **9** implements the averaging pattern of FIG. **5**B. The resultant average is delivered to the third stage Walsh-Hadamard filter **104** (FIG. **7**, n=4).

Each "collapsed" Walsh-Hadamard filter (FIG. **4**) includes a 4 by 4 Walsh-Hadamard processor **106** (FIG. **7**) which is shown in greater detail in FIG. **11**. With reference to the components of FIGS. **4**, **7** and **11**, each processor **106** includes (1) the direct transform network **74***a*, **74***b* or **74***c* (shown as a 4 by 4 direct Walsh-Hadamard transformer **108** in FIG. **11**) (2) the clipping-/removal circuits **76***a*, **76***b* or **76***c* (shown as a magnitude comparator **110** and a multiplexer **112** in FIG. **11**) and (3) the inverse transform network **78***a*, **78***b* or **78***c* (shown as a 4 by 4 inverse Walsh-Hadamard transformer **114** in FIG. **11**). The network of delay units preceding the processor **106** in the diagram of FIG. **7** corresponds to the respective delay and alignment network **70***a*, **70***b* or **70***c* utilized in the respective stages of the apparatus of FIG. **4**. The delay elements leading to the processor **106** assemble the image signals a_{ij} resulting from the block (2) of nine sampled image elements A_{ij} into an array (4) of sixteen image signals, some of which are duplicates of others. The assignment of the number n (n=1, 2 or 4) corresponds to the particular stage being assembled, each stage sampling the image in accordance with the respective patterns of FIGS. **6**A, **6**B and **6**C. The network of delay and summing units following the processor **106** in the diagram of FIG. **7** corresponds to the respective assembly and averaging network **80***a*, **80***b* or **80***c* shown in FIG. **4**.

Referring now to FIG. **11**, the sixteen input image signals $a_{11} \ldots a_{33}$ (some appearing more than once) are presented to the 4 by 4 direct Walsh-Hadamard transformer **108**, which performs a 4 by 4 Walsh-Hadamard transform on the input signals and generates sixteen transform coefficient signals $c_{11} \ldots c_{44}$. The direct Walsh-Hadamard transformer **108** as shown in FIG. **12** employs a battery of 1 by 4 arithmetic networks **116**. The schematic

4 arithmetic network **116** operating for a single 1 by arithmetic network **116** operating on four image signals is shown in FIG. **13** in which the required calculations are implemented by a set of 1 by 2 arithmetic networks **118**, each of which is composed of a summing network shown in FIG. **14**. The other 1 by 4 arithmetic networks of FIG. **12** are the same excepting the respective input and output lines.

Certain of the Walsh-Hadamard transform coefficient signals are compared to respective magnitude references (i.e., thresholds) in the magnitude comparator **110** (FIG. **11**). If any of the coefficient signals have a magnitude value exceeding the corresponding reference, a bit is set to the multiplexer **112** causing the multiplexer **112** to set the corresponding coefficient signal to zero. Otherwise the input coefficient signals are switched to the 4

by 4 inverse Walsh-Hadamard transformer **114** without change. Four of the coefficient signals—those generated by the operations within the broken line box **92** of FIG. **3**—are set to zero. For implementing the inverse Walsh-Hadamard transform, the 4 by 4 inverse Walsh-Hadamard transformer **114** is constructed the same as the 4 by 4 direct Walsh-Hadamard transformer **108** with inputs now being the twelve modified coefficient signals. The processed image signals $a'_{11} \ldots a'_{33}$ are then divided by sixteen and presented to the network of delay and summing units following the processor **106** of FIG. **7**. In this network, nine signal components (due to block/block overlap) pertaining to each image element are assembled by the arranged delay elements and averaged together.

The second and third stage "collapsed" Walsh-Hadamard filters **102** and **104** are implemented with the same arrangement of digital devices as for the first stage, the difference being that n is set to 2 and 4, respectively, to account for multiple delays in the networks preceding and succeeding the 4 by 4 Walsh-Hadamard processor **106** of FIG. **7**.

The averaged signals (now predominantly noise) from each "collapsed" Walsh-Hadamard filter stage of FIG. **4** are presented to the delay, alignment and summing network **82**, which provides delays to compensate for the delays incorporated in the respective stages, and aligns and subtracts the signals produced by the three stages from the unmodified full-band signal S presented on the line **68**. The configuration of delay and summing elements diagrammed in FIG. **10** provides the necessary delay, alignment and summing required by the network **82**, if the full-band signal and the output signals from the respective "collapsed" Walsh-Hadamard filter stages are connected as indicated.

While the disclosed embodiment of the invention describes the mapping of a 3 by 3 array of image signals—derived from a 3 by 3 block of image elements—into a 4 by 4 array of image signals suitable for 4 by 4 Walsh-Hadamard transformation, such an example is not to be construed as limiting the application of the invention. In general, the image processing method of the invention may be practiced by mapping any p by q array of image signals—derived from the light values of a p by q block of image elements—into a larger m by n array of image signals suitable for transformation by the characteristic Walsh-Hadamard combinations appropriate for the larger m by n array of signals. As one way of practicing the invention, such mapping may be accomplished in steps, by mapping the smaller p by q array into an intermediate p by n array such that two or more columns of the p by n array are duplicates of at least one column of the p by q array. Then the intermediate p by n array is mapped into the larger m by n array such that two or more rows of the m by n array are duplicates of at least one row of the p by q array. In terms of the image signal arrays already discussed, the 3 by 3 array of image signals

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

is mapped into an intermediate 3 by 4 array

$$\begin{bmatrix} a_{11} & a_{12} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{32} & a_{33} \end{bmatrix}$$

such that the second and third columns of the intermediate array are duplicates of the second column of the smaller 3 by 3 array. Then the intermediate 3 by 4 array is mapped into the larger 4 by 4 array

$$\begin{bmatrix} a_{11} & a_{12} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{22} & a_{23} \\ a_{21} & a_{22} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{32} & a_{33} \end{bmatrix}$$

such that the second and third rows of the larger 4 by 4 array are duplicates of the second row of the intermediate 3 by 4 array. Alternatively, the steps could be reversed; the middle row of the 3 by 3 array could be mapped into the middle two rows of a 4 by 3 intermediate array, followed by the middle column of the 4 by 3 array into the middle two columns of the 4 by 4 array. Clearly, these techniques may be used to convert between other than 3 by 3 and 4 by 4 arrays, e.g., between 3 by 3 or larger arrays and 5 by 5 or larger arrays, and so on. Furthermore, the invention may be practiced in one dimension, that is, by converting a 1 by q (or p by 1) signal array into a larger 1 by n (or m by 1) signal array suitable for transformation by the Walsh-Hadamard transform appropriate for the larger string of signals in that single dimension.

The invention has been described in detail with particular reference to presently preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

What is claimed is:

1. In an image processing method of the type using a Walsh-Hadamard transformation, in which image signals representative of the light value of elements of the image are grouped into arrays of signals prior to transformation, the improvement wherein the signals from each array are mapped into a larger array such that one or more image signals appear two or more times in the larger array and the signals constituting the larger array are then transformed in accordance with the Walsh-Hadamard combinations characteristic of the larger array.

2. In an image processing method of the type using a Walsh-Hadamard transformation, in which image signals representative of the light value of elements of the image are grouped into signal arrays suitable for transformation, the improvement wherein the signals comprising each said signal array originate from signals comprising a smaller array of image signals aligned to a corresponding block of image elements such that said signal array includes multiple contributions from one or more signals of said smaller array.

3. In an image processing method of the type using a Walsh-Hadamard transform, wherein a p by q array of image signals representative of the light value of a p by q block of image elements are selected for transformation, the improvement wherein the signals constituting each p by q array are mapped into a larger m by n array

such that at least one column of the p by q array is duplicated so as to provide the additional columns of the larger m by n array, and the signals constituting the larger m by n array are then transformed in accordance with the Walsh-Hadamard combinations characteristic of an m by n array of signals.

4. The method as claimed in claim **3** wherein at least one row of the p by q array is duplicated so as to provide the additional rows of the larger m by n array.

5. The method as claimed in claim **4** wherein p=q=3 and m=n=4 and wherein the p by q array is mapped into the larger m by n array by mapping the second column of the p by q array into the second and third columns of a p by n intermediate array, and then mapping the second row of the p by n intermediate array into the second and third rows of the m by n array.

6. A method of transform processing an image for noise reduction, comprising the steps of:

generating image signals representative of the light value of elements of the image;

forming the image signals into signal arrays according to patterns having predetermined locations in which the same image signal recurs in order to complete each array;

transforming each array of image signals by a set of arithmetic combinations characteristic of the Walsh-Hadamard transform into a set of coefficient signals representing combinations of image signals sensitive to a smoothed light value and to differences in light value among said image elements;

modifying one or more of the coefficient signals in order to reduce noise in the processed image; and

generating a processed image of reduced noise from said coefficient signals, some of which may have been modified.

7. the method as claimed in claim **6** wherein the step of modifying one or more of the ciefficient signals comprises the steps of (A) selecting certain coefficient signals by comparison to a threshold and (B) altering these selected coefficient signals.

8. An image processing method employing the Walsh-Hadamard transform in order to reduce noise and preserve image structure, such as edges, in a processed image, said method comprising the steps of:

generating image signals representative of the light value of specific elements of the image;

forming an enlarged array of signals suitable for transformation from a smaller number of image signals aligned to said specific elements, wherein one or more of the image signals are used more than once to occupy the additional rows and/or columns of the enlarged array;

transforming the signals constituting the enlarged array by means of the Walsh-Hadamard transform into a set of coefficient signals;

modifying the set of coefficient signals in order to reduce noise and preserve image structure, such as edges, in the processed image; and

generating a processed image from said modified set of coefficient signals.

9. The method as claimed in claim **8** wherein the enlarged array is a 4 by 4 array comprising sixteen signals and the smaller number of image signals comprises nine image signals derived from a 3 by 3 block of image elements.

10. The method as claimed in claim **8** wherein the step of modifying the set of coefficient signals comprises the steps of:

comparing the magnitude of the coefficient signals to at least one threshold of such magnitude(s) that greater coefficient magnitudes rarely occur due to noise above;

selecting coefficient signals that are less in magnitude than the said threshold(s); and

altering these selected coefficient signals by reducing their magnitudes.

11. The method as claimed in claim **8** wherein

(A) the step of generating image signals comprises additionally generating a full-band image signal that is not formed into enlarged arrays and transformed;

(B) the step of modifying the set of coefficient signals comprises the steps of:

comparing the magnitude of the coefficient signals to at least one threshold of such magnitude(s) that greater coefficient magnitudes rarely occur due to noise alone;

selecting coefficient signals that have magnitudes greater than the magnitude(s) of said threshold(s); and

altering these selected coefficient signals by reducing their magnitudes; and

(C) the step of generating a processed image comprises the steps of:

generating noise signals by inverse transforming the sets of coefficient signals, some of which have been altered in a preceding step; and

subtracting the noise signals from the full-band signal.

12. A method of transform processing an image for noise reduction and preservation of image structure, comprising the steps of:

generating image signals representative of the light value of elements of the image;

forming an m by n signal array from a p by q array of image signals, wherein the m by n array is larger than the p by q array and some image signals from the p by q array appear more than once in the m by n array;

transforming the signals constituting each m by n array by means of a m by n Walsh-Hadamard transform into a set of coefficient signals representing combinations of the image signals sensitive to noise and particular components of image structure;

modifying one or more of the coefficient signals in order to reduce noise in the processed image, thereby preserving the remaining image structure; and

generating a processed image from said coefficient signals.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,549,212
DATED : October 22, 1985
INVENTOR(S) : Bryce E. Bayer

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 12, line 53, delete "4 arithmetic network 116 operating for a single 1 by" and insert --for a single 1 by 4-- in its place.

Signed and Sealed this

Twenty-first **Day of** *January 1986*

[SEAL]

Attest:

DONALD J. QUIGG

Attesting Officer — *Commissioner of Patents and Trademarks*

United States Patent [19]
Cosh

[11] Patent Number: 4,568,978
[45] Date of Patent: Feb. 4, 1986

[54] **METHOD OF A CIRCUIT ARRANGEMENT FOR PRODUCING A GAMMA CORRECTED VIDEO SIGNAL**

[75] Inventor: **Ian S. Cosh**, Cambridge, England

[73] Assignee: **U.S. Philips Corporation**, New York, N.Y.

[21] Appl. No.: **504,103**

[22] Filed: **Jun. 15, 1983**

[30] **Foreign Application Priority Data**

Jun. 30, 1982 [GB] United Kingdom 8218883
Apr. 5, 1983 [GB] United Kingdom 8309208

[51] **Int. Cl.**[4] **H04N 5/20**
[52] **U.S. Cl.** **358/164**; 358/32; 358/169; 328/145
[58] **Field of Search** 358/32, 164, 169; 328/145

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,394,688 7/1983 Iida et al. 358/164
4,499,494 2/1985 Dischert et al. 358/164

OTHER PUBLICATIONS

SMPTE Journal, vol. 88, "A Digital Telecine Processing Channel", by Oliphant et al, pp. 470–480, (7–79).
IEEE Transactions on Broadcasting, vol. BC–22, No. 4, "On the Use of a Television System in Image Reproduction: Part 1–The Image Processing System", by Lappalainen et al, pp. 109–112, (12–76).

Primary Examiner—Tommy P. Chin
Assistant Examiner—Michael D. Parker
Attorney, Agent, or Firm—Thomas A. Briody; William J. Streeter; Marianne Rich

[57] **ABSTRACT**

A gamma correction factor is applied to a video signal without need of the normally used multiplier by forming the logarithm of the logarithm of the video signal and algebraically adding this signal to a second signal representing the logarithm of the correction factor. The anti-log of the anti-log of the resulting signal constitutes the gamma corrected signal. Analog and digital implementations of the circuitry are illustrated.

10 Claims, 4 Drawing Figures

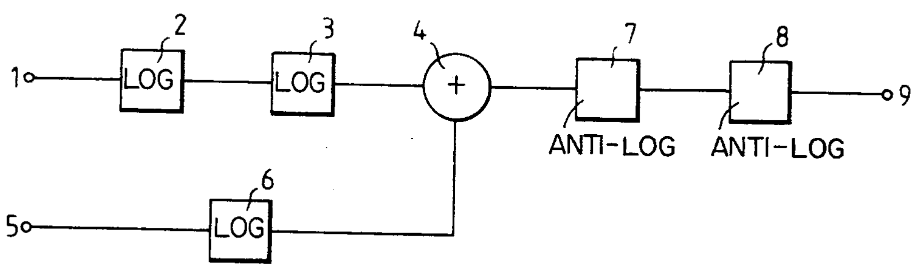


Fig. 1.

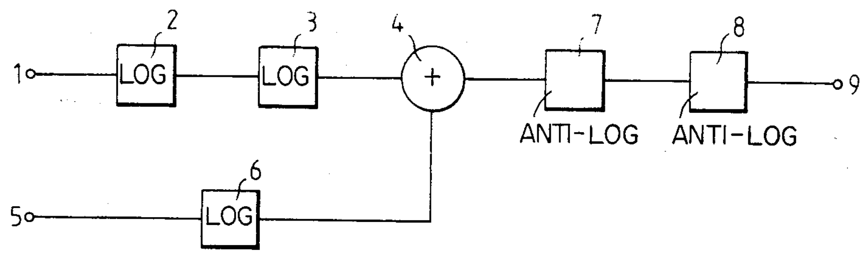


Fig. 2.

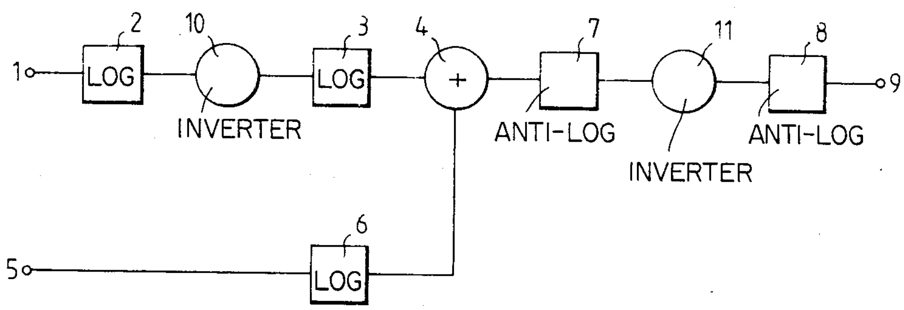


Fig. 3.

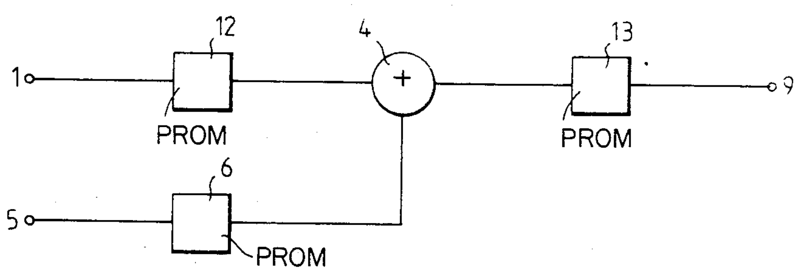
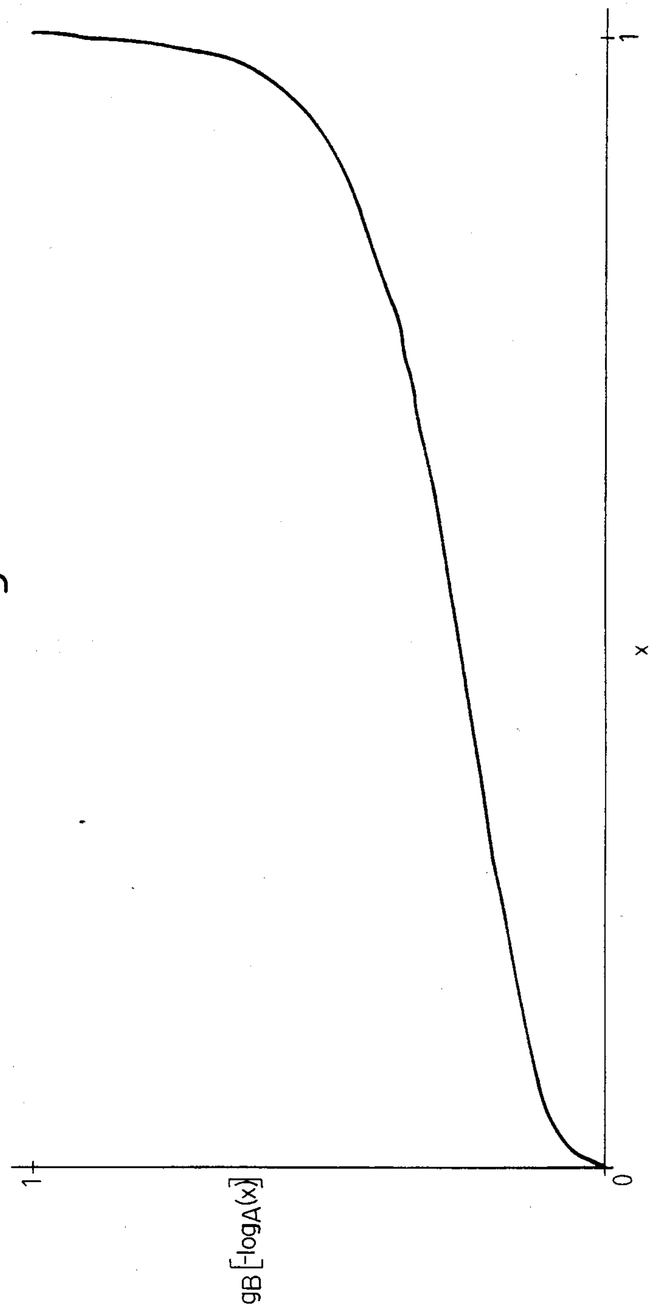


Fig. 4.



METHOD OF A CIRCUIT ARRANGEMENT FOR PRODUCING A GAMMA CORRECTED VIDEO SIGNAL

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a method of and a circuit arrangement for producing a gamma corrected video signal.

2. Description of the Prior Art

Display tubes for television introduce a distortion of the picture information due to a non-linear relationship between the applied signal voltage and the resulting screen brightness. This relationship may be approximated by the expression

$$Lo-K\ V_s\ \delta$$

where

Lo=Light output

K=constant

V_s=applied signal voltage

δ=constant, known as gamma.

Typically δ has a value of 2.5 whereas ideally it would be 1.0.

To prevent this distortion becoming apparent to the viewer the video signal is transmitted in a modified form by passing the signal through a gamma correction circuit which introduces a complementary distortion.

The modification carried out by a gamma corrector may be described by the expression

$$V_s = V_i^{1/\delta} = V_i^G$$

where

V_s=output signal for transmission

V_i=input signal requiring modification

δ=constant, as before.

In practice the value of δ employed in the gamma correction circuit may not be exactly 2.5 but chosen to give the best subjectively pleasing result.

It is sometimes necessary, for example in television cameras, to perform the inverse operation to derive an uncorrected signal from a previously gamma corrected signal. In this specification the term gamma correction is to be understood to include both the correction of an uncorrected signal and the derivation of an uncorrected signal from a corrected signal.

Gamma correction is normally achieved by first converting the input signal into its logarithm, then multiplying this signal by the desired correction factor G, and finally applying the resultant signal to an exponential or anti-logarithm converter. Such an arrangement is disclosed in an article entitled "Transistorised Non-Linear Function Generation" by P. Kundu and S. Banerji which was published in Industrial Electronics, January 1964 at pages 35 to 41.

If the signals are expressed in digital form, as is increasingly common, the same approach can be followed except that logarithmic and exponential conversion may then be achieved by means of 'look-up' tables stored in programmable read only memories (PROMs). Some difficulty is encountered, however, with the multiplication process which must be performed on each digital sample within the sample period, typically 75 ns. The digital signal, after conversion into its logarithm, may be 12 bits wide and the correction coefficient, G, 6 or more bits wide. The multiplication of a 12 bit number by a 6 bit number within 75 ns entails either complex circuitry to form and add partial products, or the use of integrated circuit multipliers which consume considerable power and are relatively expensive.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a method of a gamma correcting a television signal which does not require the use of a multiplier circuit, and to enable the production of a circuit arrangement for performing the method.

The invention provides a method of gamma correcting (as hereinbefore defined) a video signal comprising the steps of: forming a first signal representative of the logarithm of the logarithm of the video signal; forming a second signal of representative of the logarithm of the correction factor; forming a third signal representative of the algebraic sum of the first and second signals; and forming a fourth signal representative of the exponential of the exponential of the third signal, the fourth signal being the gamma corrected signal.

The invention further provides a circuit arrangement for gamma correcting (as hereinbefore defined) a video signal applied to an input thereof comprising means for forming a first signal representative of the logarithm of the logarithm of the input signal, means for forming a second signal representative of the logarithm of the correction factor, means for forming a third signal representative of the algebraic sum of the first and second signals, means for forming a fourth signal representative of the anti-logarithm of the exponential of the third signal, and means for feeding the fourth signal to an output of the circuit arrangement as the gamma corrected signal.

The circuit arrangement may be such that the first signal P is equal to $\log_B(-\log_A V_i)$ where V_i is the input signal, the second signal Q is equal to $\log_B G$ where G is the correction factor, the third signal R is equal to $P \pm Q$, and the fourth signal is equal to $A \exp(-B \exp R)$, where A and B are constants.

This method and circuit arrangement enables the multiplier of prior art arrangements to be replaced by an adder or a subtractor as appropriate. Where digital signals are employed adders and subtractors can be fabricated more cheaply than multipliers and can operate more quickly. The sampling rate agreed by the European Broadcasting Union for digital television standards is 13.5 MHz which means that the time available for processing each sample is less than 75 nSecs.

When the video signal V_i is in digital form the first, second and third means may comprise programmed digital memory devices which digital memory devices may comprise programmable read only memories.

This enables a relatively simple construction from readily available standard integrated circuits.

When choosing the bases for the logarithms it is convenient to make A equal to 2^n where n is the number of bits in each sample of the input signal. B may be conveniently chosen to be equal to 10^x where $x=[\log_{10}(-\log_A A-1/A)]$.

It may be noted that in a gamma correction circuit which comprises a read only memory code converter is disclosed in a paper entitled "Digital Processing Amplifier and Colour Encoder" by Yoshizumi Eto, Kazuyuki Matsui, Shizuka Ishibashi, and Hiroyuki Terui which was published in SMPTE Journal, Volume 87, January 1978, pages 15 to 19. However the arrangement de-

scribed therein will only produce a fixed gamma correction it not being possible to alter the correction factor.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** illustrates in block schematic form the principle of gamma correction according to the invention,

FIG. **2** shows in block schematic form a first embodiment of a circuit arrangement for gamma correcting an input video signal according to the invention,

FIG. **3** shows in block schematic form a second embodiment of a circuit arrangement for gamma correcting an input video signal according to the invention, and

FIG. **4** is a graph of the function $y=[\log_B(-\log_A(x))]$.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** illustrates the principle used in the invention for producing a modified signal which does not involve the use of multipliers and comprises an input **1** for a video signal V_i which input is connected to a log conversion unit **2** for producing a first output equal to $\log_A V_i$. The output of unit **2** is connected to a log conversion unit **3** for producing a second output signal equal to $\log_B(\log_A V_i)$. The second output signal is applied to a first input of an adder **4**. A correction factor G is connected via a second input **5** of the arrangement to a unit **6** which produces a third output signal equal to $\log_B G$, the third output signal being connected to a second input of the adder **4**. The adder **4** produces a fourth output signal equal to $\log_B(\log_A V_i)+\log_B G$ which is fed to an antilog conversion unit **7** which produces a fifth output signal equal to $G \log_A V_i$. The fifth output signal is fed to an antilog conversion unit **8** which produces a sixth output signal equal to V_i^G which sixth output signal is applied to an output terminal **9** of the arrangement.

Since in a television signal the black level and peak white level must remain at defined amplitudes it is necessary to define the input signal V_i as being in the range of $0 \leqq V_i \leqq 1$. However, since the logarithm of a number having a value between 0 and 1 is always negative it is not possible to find the second logarithm $[\log_B(\log_A V_i)]$ since, mathematically, there is no logarithm of a negative number.

However, in this case, for the purpose of achieving the multiplication function the sign of the multiplicand may be ignored and the multiplicand treated as a positive number even though it is in fact negative. This applies in this case since the multiplicand is always negative and the multiplier G is always positive; consequently the product is always negative.

This procedure is shown functionally in FIG. **2** in which those items having the same functions as corresponding items in FIG. **1** have been given the same reference numerals. In the arrangement shown in FIG. **2** a unit **10** is added which multiplies the output of unit **2** by -1 to give an output signal equal to $-\log_A V_i$ which means in turn that the first input of the adder **4** receives a signal equal to $\log_B(-\log_A V_i)$. As a result the output of the adder is equal to $\log_B(-\log_A V_i)+\log_B G$ and the output of unit **7** is equal to $-G \log_A V_i$. This signal is then multiplied by -1 in a unit **11** to give an output $G \log_A V_i$ which is then applied to the unit **8**.

If the input signal V_i is in analog form the log and antilog conversion units may be realised as amplifiers having logarithmic and exponential characteristics respectively, the units **10** and **11** by inverting amplifiers, and the adder **4** as a summing amplifier.

If the input signal V_i is in digital form then the log and antilog conversion units may be formed as programmable read only memories (PROMS) and the units **10** and **11** may be incorporated in the respective PROM since their only effect is to change the sign of the output. In practice, with a digital input signal a further simpliciation can be made as illustrated in FIG. **3**. In the arrangement shown in FIG. **3** a PROM **12** replaces units **2**, **3** and **10** and a PROM **13** replaces unit **7**, **8** and **11**. The arrangement then simplifies to three PROMS **6**, **12** and **13** and an adder **4**. With this arrangement the PROM **12** is programmed to give an output equal to $[\log_B(-\log_A V_i)]$ in response to an input signal V_i, the PROM **6** is programmed to give an output equal to $\log_B G$ in response to an input signal G, and the PROM **13** is programmed to give an output A exp]$-$B exp (R)] where $R=P+Q$ $P=\log_B(-\log_A V_i)$, and $Q=\log_B G$.

The embodiments described may be modified to perform the inverse function, that is to convert a previously gamma corrected signal into an uncorrected signal or $V_s=V_i^{1/G}$. The only modification required is to replace the adder **4** by a subtractor so that at the output of the subtractor the function $\log_B(-\log_A V_i)-\log_B G$ is formed. Such an inverse operation may be useful within television camera circuits or in special effects generators.

The choise of logarithm bases A and B is arbitrary but there are certain values which ease implementation.

If base A is related to the resolution of the input variable, V_i, the dependent variable P can be made positive for all non-zero values of V_i. V_i may, for example, be a ten bit binary number representing values in the range

$$\frac{0}{1024} \leqq V_i \leqq \frac{1023}{1024}$$

If base A is chosen as 2^{10}, that is 1024, then the intermediate variable, $I=[-\log_{1024}(V_i)]$ varies between 0.00014095 and 1.0 as V_i varies between 1023/1024 and 1/1024.

The zero value, $V_i=(0/1024,)$ is a special case, discussed hereinafter.

The second logarithm base, B, acts as a scaling constant and is conveniently chosen such that

$$0 \leqq P \leqq 1 \text{ for } \frac{0}{1024} \leqq V_i \leqq \frac{1023}{1024}$$

This is achieved by making

$$B=10^x$$

where $x=[\log_{10}(-\log_{1024}(1023/1024))]$ rounded up. For the values given $B=7095$.

The general form of the fuction

$$y=[\log_B(-\log_A(x))]$$

is as shown in FIG. **4**.

By differential calculus it can be shown that the minimum gradient if the function $y=[\log_B(-\log_A(x))]$

occurs for a value of $x=1/e$. At this point the gradient of the function is

$$\text{gradient}_{min} = \frac{e}{\log_e B} = .3066\ (B = 7096)$$

For each input code to translate to a unique output code the output code must have four times the resolution of the input code. Consequently if the input is defined by ten bits, the output should have twelve bits. If the value of $[\log_B G]$ is subtracted instead of added then inverse operation is achieved, i.e. the output signal becomes

$$V_S = V_i^{(1/\delta)}$$

In practice certain circumstances require special attention when the input value $V_i=0$ the output V_s must also be zero. This can be done by detecting the zero value of the input code either by a multiple input 'NOR' gate having one input for each input bit or by using an extra output from PROM **12**. When the zero input code is detected the output code, V_s, can be artificially forced to zero.

For large values of V_i the adder may overflow. This is readily detected by sensing the 'carry-out' output of the adder. In the event of overflow the output, V_s, must be artificially forced to unity. Conversely, if inverse operation is being done then the state of 'underflow' of the subtractor must be sensed and the output, V_s, forced artificially to zero.

I claim:

1. A method of correcting a video signal by a gamma correction factor, comprising the steps of:

forming a logarithm of a logarithm of said video signal, thereby creating a first signal;

forming a logarithm of said correction factor, thereby creating a second signal;

algebraically adding said first and second signals, thereby forming a third signal; and

forming an anti-logarithm of an anti-logarithm of said third signal, thereby creating a fourth signal, said fourth signal constituting said video signal corrected by said gamma correction factor.

2. A method as claimed in claim **1**, wherein said first signal (P) is equal to $\log_B(-\log_A V_i)$ where V_i is said

video signal, wherein said second signal (Q) is equal to $\log_B G$ where G is said correction factor, wherein said third signal (R) is equal to $P\pm Q$, and said fourth signal is equal to $A \exp(-B \exp R)$, where A and B are constants.

3. A method as claimed in claim **2**, in which the video signal is in digital form and A is equal to 2^n where n is the number of bits defining the amplitude of the video signal.

4. A method as claimed in claims **2** or **3** wherein $B=10^x$ where $x=\log_{10}[-\log_A(A=1/A)]$.

5. A circuit arrangement for correcting a video signal applied to an input thereof by a gamma correction factor comprising means for forming a first signal representative of a logarithm of a logarithm of said video signal, means for forming a second signal representative of a logarithm of said correction factor, means for forming a third signal representative of the algebraic sum of said first and second signals, means for forming a fourth signal representative of an anti-logarithm of an anti-logarithm of said third signal, and means for feeding said fourth signal to an output of the circuit arrangement as said video signal corrected by said gamma correction factor.

6. A circuit arrangement as claimed in claim **5**, wherein said first signal (P) is equal to $\log_B(-\log_A V_i)$ where V_i is said video signal, said second signal is equal to $\log_B G$ where G is said correction factor, said third signal (R) is equal to $P\pm Q$, and said fourth signal is equal to $A \exp(-B \exp R)$, where A and B are constants.

7. A circuit arrangement as claimed in claim **5** or claim **6**, in which said video signal is in digital form, and wherein the first, second and third means comprise programmed digital memory devices.

8. A circuit arrangement as claimed in claim **6**, in which $A=1024$.

9. A circuit arrangement as claimed in claim **6**, in which $B=10^x$ where $x=[\log_{10}(-\log_A(A-1/A)]$.

10. A circuit arrangement as claimed in claim **5**, in which the resolution of said gamma corrected signal is four times that of said video signal.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 4,568,978

DATED : February 4, 1986

INVENTOR(S) : Ian S. Cosh

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Claim 4 Col 6 Line 10 change " $-\mathrm{Log}_A(A=1/A)$ " to

-- $-\log_A\left(\frac{A-1}{A}\right)$ --

Claim 9 Col 6 Line 41 change "(A-1/A)" to -- $\left(\frac{A-1}{A}\right)$

Signed and Sealed this

Twenty-second Day of March, 1988

Attest:

DONALD J. QUIGG

Attesting Officer *Commissioner of Patents and Trademarks*

United States Patent [19]

Shenk

[11] **Patent Number: 4,663,667**

[45] **Date of Patent: May 5, 1987**

[54] **CONTRAST CONTROL CIRCUIT**

[75] Inventor: **Edwin K. Shenk**, Westford, Mass.

[73] Assignee: **Polaroid Corporation**, Cambridge, Mass.

[21] Appl. No.: **801,689**

[22] Filed: **Nov. 25, 1985**

[51] **Int. Cl.**^{4} **H04N 5/57**

[52] **U.S. Cl.** **358/169**; 358/168; 358/284

[58] **Field of Search** 358/280, 284, 168, 169, 358/166

[56] **References Cited**

U.S. PATENT DOCUMENTS

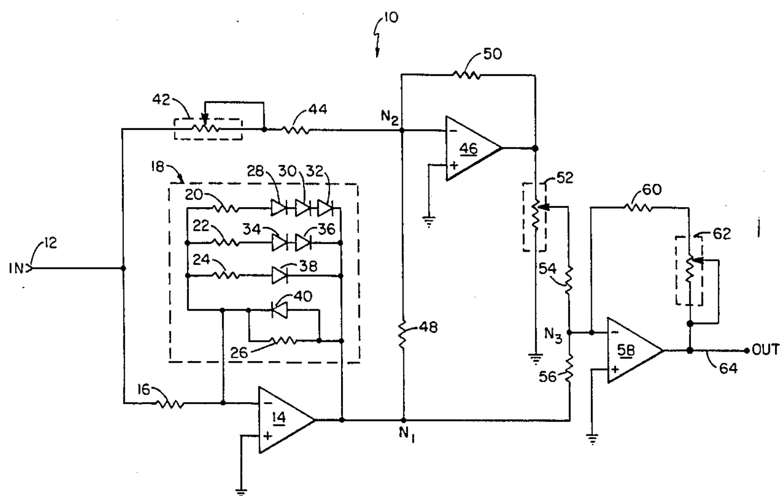
3,804,981	4/1974	Avins	358/168
4,213,155	7/1980	Miienchow	358/284
4,279,003	7/1981	Schulz	358/284

Primary Examiner—Tommy P. Chin
Attorney, Agent, or Firm—Edward S. Roman

[57] **ABSTRACT**

A contrast control circuit for use in an electronic image printing system for adjusting the contrast of an analog electronic image information signal without changing the maximum and minimum brightness levels thereof in order to maintain the exposure of a photosensitive material such as photographic film within its determined range of sensitivity.

6 Claims, 6 Drawing Figures



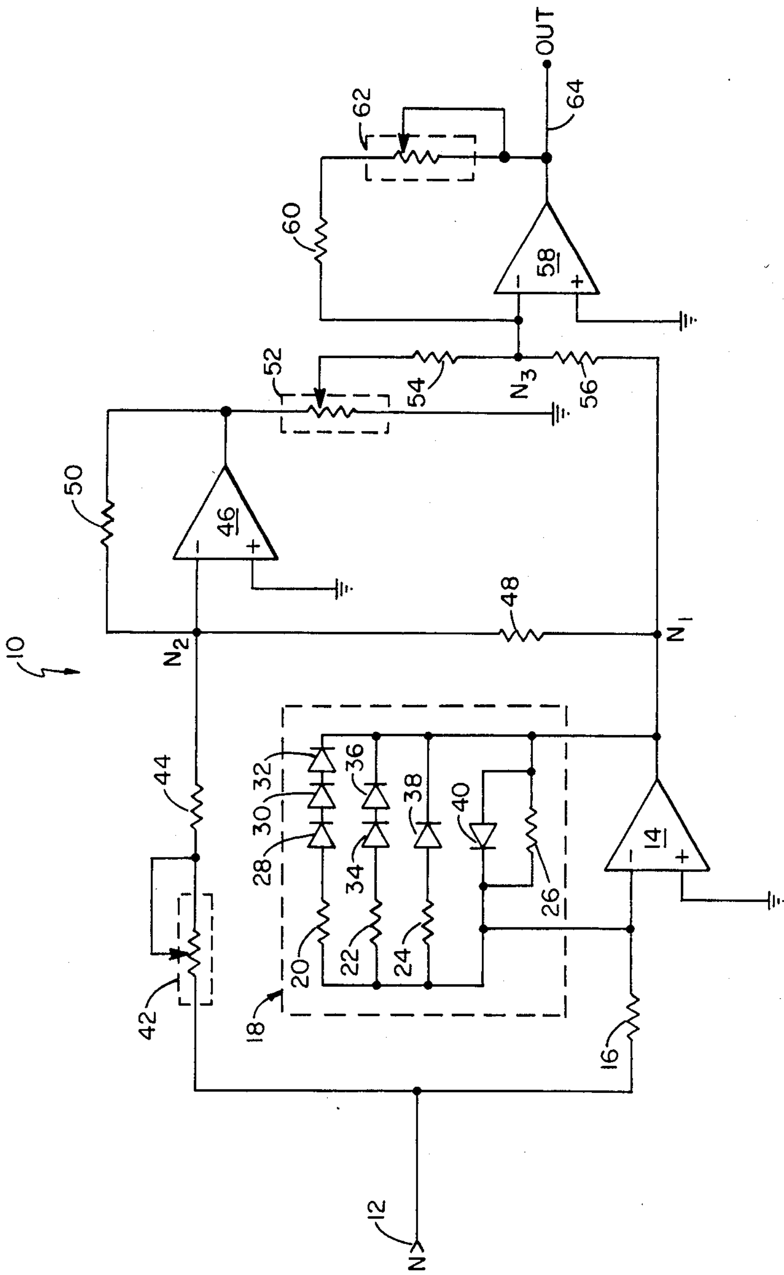

OUT
64
62
60
58
52
54
N3
56
50
46
48
10
N2
N1
44
42
18
20
22
24
26
28
30
32
34
36
38
40
14
16
12
IN

FIG 1

FIG 2A

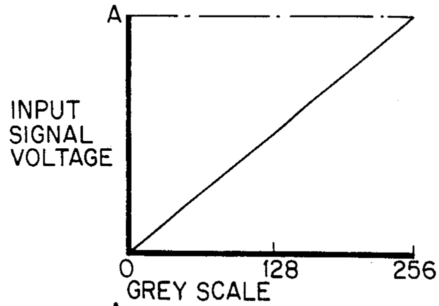


FIG 2B

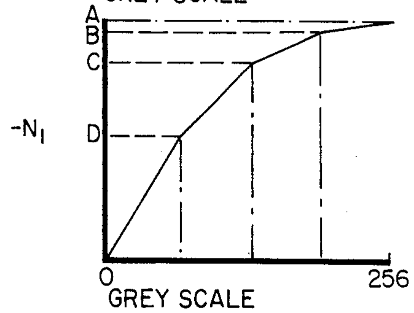


FIG 2C

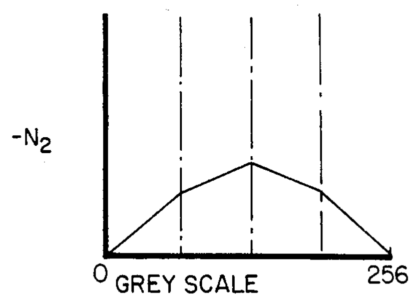


FIG 2D

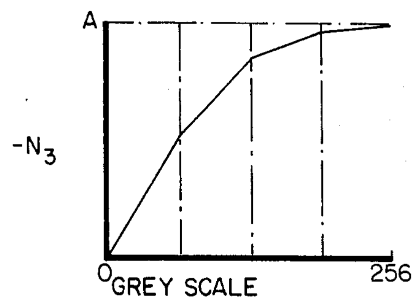
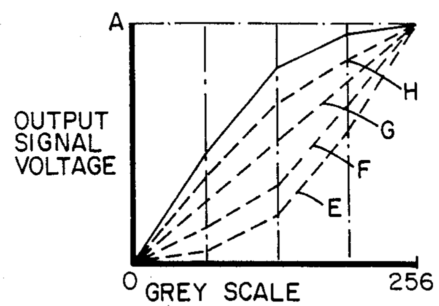


FIG 2E



CONTRAST CONTROL CIRCUIT

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to a contrast control circuit and, more particularly, to a contrast control circuit for adjusting the contrast of an analog electronic image information signal without changing its brightness range.

2. Description of the Prior Art

Electronic image printing devices for electronically printing an image on a photosensitive material such as a photographic film are well known in the art. Such devices may utilize a cathode ray tube (CRT) which responds to an analog electronic image information signal to expose a photosensitive material and thereby record the desired image. Alternatively, photosensitive materials may be exposed by laser beams scanned across the face thereof or light emitting diode arrays both of which are well known in the art. In addition, other means for converting an analog electronic image information signal to a hard copy by exposing a photosensitive material to either light or thermal energy are well known in the art.

Such photosensitive materials and in particular photographic films have determinate ranges of sensitivity to which the exposing light or thermal energy must be matched thereby requiring the exposure to take place within a select range of brightness values. However, it may also be desirable to vary the contrast of the image recorded on the photosensitive material which generally cannot be achieved without having some effect on the brightness range to which the photosensitive materials are exposed.

Therefore, it is a primary object of this invention to provide a contrast control circuit for use in an electronic image copying system for adjusting the contrast of an analog electronic image information signal without changing the brightness range thereof.

It is a further object of this invention to provide a contrast control circuit for use in an electronic image printing system for adjusting the contrast of an analog electronic image information signal without changing the selected maximum and minimum brightness levels thereof thereby maintaining the exposure of a photosensitive material such as photographic film within its selected range of sensitivity.

Other objects of the invention will be in part obvious and will in part appear hereinafter. The invention accordingly comprises a circuit possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure.

SUMMARY OF THE INVENTION

A contrast control circuit is provided for adjusting the contrast of an analog electronic image information signal without changing the select maximum and minimum brightness levels of the analog electronic image information signal. The contrast control circuit comprises means for receiving an input analog electronic image information signal for amplification in a non-linear manner. The input analog electronic image information signal is also combined with the non-linearly amplified analog electronic image information signal in a manner to provide a first modified analog electronic image information signal corresponding to the difference between the non-linear amplified analog electronic image information signal and the input analog electronic image information signal. Means are provided for receiving the first modified analog electronic image information signal for amplification in a select linear manner and for combining the linearly amplified first modified analog electronic image information signal with the non-linearly amplified analog electronic image information signal in a manner to provide a second modified analog electronic image information signal corresponding to the difference between the non-linearly amplified analog electronic image information signal and the linearly amplified first modified analog electronic image information signal. Means are provided for receiving the second modified analog electronic image information signal for amplification in a select linear manner to provide an output analog electronic image information signal, the contrast of which may be selectively varied in correspondence with the select linear manner in which the amplification of the first modified analog electronic information signal is varied.

DESCRIPTION OF THE DRAWINGS

The novel features that are considered characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with other objects and advantages thereof will be best understood from the following description of the illustrated embodiment when read in connection with the accompanying drawings wherein:

FIG. **1** is a schematic circuit diagram of the contrast control circuit of this invention; and

FIGS. 2A–2E show, respectively, the response curves for the analog electronic image information signal voltage levels versus grayscale at various nodes and terminals of the contrast circuit of FIG. **1**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. **1**, there is shown generally at **10** the contrast control circuit of this invention comprising an input terminal **12** for receiving an analog electronic image information signal. The input terminal **12** connects by way of an input resistor **16** to the negative input terminal of a first operational amplifier **14**, the positive input terminal to which is grounded. A feedback network as shown generally at **18** connects the negative input terminal of the operational amplifier **14** to the output terminal. The feedback network **18** comprises a first resistor **20** in serial connection with three diodes **28**, **30** and **32**, a second resistor **22** in serial connection with two diodes **34** and **36**, a third resistor **24** in serial connection with one diode **38** and a fourth resistor **26** in parallel connection with one diode **40**. Thus, there are provided four distinct feedback paths which are biased into conduction at different times in a manner as will be fully described in the following discussion.

The output signal from the operational amplifier **14** at node N_1, in turn, is directed by way of a resistor **48** to node N_2. The input terminal **12** also connects by way of a calibration potentiometer **42** and series resistor **44** to the node N_2. The node N_2 is also in common connection with the negative input terminal of a second operational amplifier **46**, the positive input terminal to which is grounded. The operational amplifier **46** has a fixed feed-

back resistor **50** connected from the negative input terminal thereof at node N_2 to the output terminal thereof. The output terminal from the operational amplifier **46**, in turn, connects to one side of a contrast control potentiometer **52** of which the other side is grounded as shown in the drawing. The variable slider of the potentiometer **52**, in turn, connects by way of a resistor **54** to node N_3 which also is connected to the node N_1 by way of an interconnecting resistor **56**. The node N_3, in turn, connects to the negative input terminal of a third operational amplifier **58**, the positive input terminal to which is grounded. The operational amplifier **58** has a feedback network comprising a brightness control potentiometer **62** in serial connection with a resistor **60**. The output from the operational amplifier **58** provides the output analog electronic image information signal in which the brightness and contrast are selectively varied in the manner of this invention to be now described.

Referring now to FIGS. **2A–2E** and in particular FIG. **2A**, there is shown a graphical representation for the response characteristic of the input signal voltage level of the analog electronic image information signal versus grayscale. As will be readily understood by those of ordinary skill in the art, the grayscale comprises a series of gray tones extending in regular steps of increased scene depth of tone from light or clear, as shown at **0**, to black or opaque, as shown at **256**. Thus, the correlation between the voltage level of the input analog electronic image information signal and the grayscale of the photosensitive material upon which the image is to be ultimately produced is linear.

The input analog electronic image information signal is amplified in a non-linear manner by the operational amplifier **14** and its associated feedback network **18** so as to provide the output response as shown in FIG. **2B**. As will be readily understood, the operational amplifier **14** is connected in a manner so as to invert the voltage polarity of the output signal so that the graph of FIG. **2B** shows the negative response at node N_1. As is readily apparent from the graph of FIG. **2B**, the non-linear gain characteristic is initially linear for voltage levels of the analog electronic image information signal from 0 volts to D volts whereupon at voltage level D the slope of the linear gain characteristic changes. The slope of the linear gain characteristic then remains constant between the analog electronic image information signal voltage levels D and C again changing at voltage level C. The slope of the linear gain characteristic thereafter remains constant between the analog electronic image information signal voltage levels C and B again changing at voltage level B and remaining constant until reaching the highest voltage level A.

Thus, it can be seen that the non-linear gain characteristic of the operational amplifier **14** comprises four distinct segments of linear gain characteristic having different slopes with each linear gain characteristic corresponding to a determined range of analog electronic image information signal voltage levels. The first linear gain characteristic in the range of analog electronic image information signal voltages from 0 to D occurs prior to the feedback diodes **28, 30, 32, 34, 36** and **38** being sufficiently forwardly biased to conduct. Diode **38** is forwardly biased into conduction when the analog electronic image information signal voltage level reaches level D to change the slope of the linear gain characteristic. Similarly, the slope of the linear gain characteristic is again changed when the analog electronic image information signal level reaches level C so as to bias the diodes **34** and **36** into forward conduction. In like manner the slope of the linear gain characteristic is again changed when the analog electronic image information signal level reaches level B so as to bias the diodes **28, 30** and **32** into forward conduction. Although four linear gain characteristic slopes are illustrated, it will be well understood that the non-linear gain characteristic can be divided into any number of linear gain segments depending upon the number of serially connected resistors and diodes that are parallel connected in the feedback network **18**. It will also be well understood that other types of well-known feedback networks could alternatively be used to establish a non-linear gain characteristic of the operational amplifier **14** as shown graphically in FIG. **2B**.

The output analog electronic image information signal from the operational amplifier **14**, in turn, is directed by way of resistor **48** to node N_2 for combination with the input analog electronic image information signal which is directed to node N_2 by way of calibration potentiometer **42** and series resistor **44**. The response curve for the combined analog electronic image information signal at node N_2 is shown graphically in FIG. **2C** where as a result of the aforementioned polarity inversion provided by the operational amplifier **14**, the voltage level of the ordinate is illustrated in negative polarity. The analog electronic image information signal at node N_2 is thereafter linearly amplified and inverted by the operational amplifier **46** in cooperation with feedback resistor **50**. The output signal from the operational amplifier **46**, in turn, is directed to the contrast control potentiometer **52** from whence a select proportion of the voltage signal level is directed by way of the potentiometer **52** slider and series resistor **54** to node N_3.

The non-linearly amplified analog electronic image information signal output from the operational amplifier **14** is also directed by way of the series resistor **56** to node N_3 for combination with the output signal from the operational amplifier **46** to provide the output response curve as shown in FIG. **2D**. Again, as will be readily understood, since the operational amplifiers **14** and **46** both operate to invert the polarity of the input signals thereto, the voltage level response curve of FIG. **2D** is shown as having its polarity inverted. The analog electronic image information signal at node N_3, in turn, is directed to the negative input terminal of the operational amplifier **58** which operates to impose a linear gain transfer characteristic thereto to provide the output analog electronic image information signal as shown at the terminal **64**.

The response curve for the output analog electronic image information signal is shown in solid lines in FIG. **2E** and may be varied within the envelope defined between the solid line response curve and the phantom line response curve as shown at E. As will now become readily apparent, the appropriate response curve as defined between the limits as shown in FIG. **2E** may be selectively chosen by appropriately adjusting the variable contrast control potentiometer **52** which effectively determines the gain of the operational amplifier **46**. Thus, under conditions where a low contrast is required, the slider of the potentiometer **52** is adjusted to achieve the lowest resistance connection to the output terminal from the operational amplifier **46** thereby in effect increasing the gain of the operational amplifier to provide the solid line output response as shown in

FIG. 2E. It will be readily understood that reducing the slope of the response curve of FIG. 2E toward the white end of the grayscale while simultaneously increasing the slope of the response curve toward the black end of the grayscale will operate to achieve a low contrast. Conversely, if a high contrast is desired, the slider of the potentiometer **52** is adjusted to provide the maximum resistance from the output of the operational amplifier **46** thereby in effect reducing the gain of the operational amplifier **46** to provide the output response as shown at phantom line at E of FIG. 2E. It will be readily understood by those having ordinary skill in the art that the response curve E of FIG. 2E having a high slope toward the white end of the grayscale and a low slope toward the dark or black end of the grayscale effects an increase in the contrast of the output analog electronic image information signal. It will also be well understood that any intermediate contrast may also be provided by adjusting the slider of the potentiometer **52** at the appropriate intermediate positions to provide the response curves as shown at phantom lines at F, G and H. The linear response curve of FIG. 2A can also be duplicated as shown by the phantom line G upon the appropriate intermediate setting for the slider of the potentiometer **52**.

It will also be appreciated from FIG. 2E that the variation in contrast can be achieved without a change in the maximum and minimum brightness levels as shown at **0** and A, respectively. The **0** or black brightness level is fixed; however, the maximum or white brightness level as shown at A may be varied by adjusting the brightness control potentiometer **62** to vary the linear gain characteristic of the operational amplifier **58**. The brightness control is accomplished entirely independently of the contrast control without effecting the contrast control settings regardless of whether the contrast control potentiometer **52** slider is adjusted to its maximum or minimum settings or any other intermediate setting. Thus, in this manner, there is provided a means for adjusting both the contrast and brightness of an analog electronic image information signal entirely independent of each other as is particularly advantageous in electronic imaging devices which expose photosensitive materials of determinate light sensitivity characteristics to provide hard copy.

It will be well understood that although the operational amplifiers **14**, **46** and **58** have been described as being connected to invert the polarity of the signals input thereto, it will be equally apparent that invertors apart from the operational amplifiers could be utilized and the operational amplifiers could be connected so as not to effect the polarity inversions as described. In addition, instead of connecting the operational amplifiers to effect polarity inversion or using separate invertors, it would be possible to substitute subtractors at the appropriate nodes where signal combinations occur.

Other embodiments of the invention including additions, subtractions, deletions and other modifications of the preferred disclosed embodiments of the invention will be obvious to those skilled in the art and are within the scope of the following claims.

What is claimed is:

1. A contrast control circuit for adjusting the contrast of an input analog electronic image information signal

without changing select maximum and minimum brightness levels for said analog electronic image information signal, said contrast control circuit comprising:

means for receiving said input analog electronic image information signal for amplification in a non-linear manner;

a first means for combining the non-linearly amplified analog electronic image information signal with the input analog electronic image information signal in a manner to provide a first modified analog electronic image information signal corresponding to the difference between the non-linearly amplified analog electronic image information signal and the input analog electronic image information signal;

means for receiving the first modified analog electronic image information signal for amplification in a select linear manner;

a second means for combining the select linearly amplified first modified analog electronic image information signal with the non-linearly amplified analog electronic image information signal in a manner to provide a second modified analog electronic image information signal corresponding to the difference between the non-linearly amplified analog electronic image information signal and the linearly amplified first modified analog electronic image information signal;

means for receiving the second modified analog electronic image information signal for amplification in a select linear manner to provide an output analog electronic image information signal; and

means for selectively varying the contrast of said output analog electronic image information signal in correspondence with the select linear manner in which the first modified analog electronic image information signal is amplified.

2. The contrast control circuit of claim **1** wherein said means for amplifying in a non-linear manner comprises a first operational amplifier and a feedback network operative to change the gain characteristic of said first operational amplifier in a non-linear manner.

3. The contrast control circuit of claim **2** wherein said feedback network comprises a plurality of serially connected resistors and diodes connected in parallel relation with respect to each other.

4. The contrast control circuit of claim **2** wherein said means for amplifying the first modified analog electronic image information signal comprises a second operational amplifier and said means for selectively varying the contrast comprises a variable output resistor that may be selectively adjusted to determine said select linear manner of amplification.

5. The contrast control circuit of claim **4** wherein said means for amplifying the second modified analog electronic image information signal comprises a third operational amplifier and a variable feedback resistor that may be selectively adjusted to determine the maximum brightness level for the output analog electronic image information signal.

6. The contrast control circuit of claim **5** wherein said first, second, and third operational amplifiers operate to invert the polarity of the output signals therefrom.

* * * * *

United States Patent [19]

Pilot

[11] **Patent Number: 4,751,566**

[45] **Date of Patent: Jun. 14, 1988**

[54] **METHOD AND DEVICE FOR GAMMA CORRECTION IN MULTICHROME CATHODE RAY TUBES**

[75] Inventor: **Alain Pilot,** Voisins Le Bretonneux, France

[73] Assignee: **Societe Francaise d'Equipements pour la Navigation Aerienne (S.F.E.N.A.),** Velizy Villacoublay, France

[21] Appl. No.: **30,649**

[22] Filed: **Mar. 26, 1987**

[30] **Foreign Application Priority Data**

Apr. 4, 1986 [FR] France 86 04836

[51] **Int. Cl.**[4] **H04N 9/69**

[52] **U.S. Cl.** **358/32;** 258/164

[58] **Field of Search** 358/32, 164, 29, 27, 358/28, 168

[56] **References Cited**

U.S. PATENT DOCUMENTS

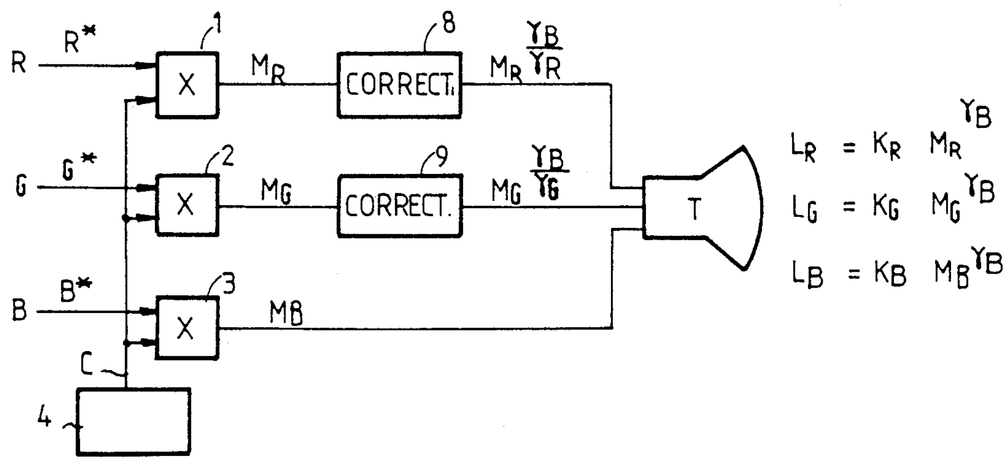
3,684,825	8/1972	Dischert et al.	358/32 X
4,415,923	11/1983	Noda	358/32 X
4,489,349	12/1984	Okada	358/32 X

Primary Examiner—James J. Groody
Assistant Examiner—Victor R. Kostak
Attorney, Agent, or Firm—William A. Drucker

[57] **ABSTRACT**

A gamma correction method and device are provided for multichrome cathode ray tubes, including, for each of the n-1 electron guns of the tube, a correction circuit adapted for raising the cathode modulation of this gun to a power $\gamma ref/\gamma_i$ in which the term γ_{ref} is the gamma exponent of the nth gun which is taken as reference and the term γ_i is the gamma exponent of the gun considered. With this device the chromaticity of the colors displayed on the screen are conserved throughout the whole contrast dynamics of the tube.

10 Claims, 3 Drawing Sheets



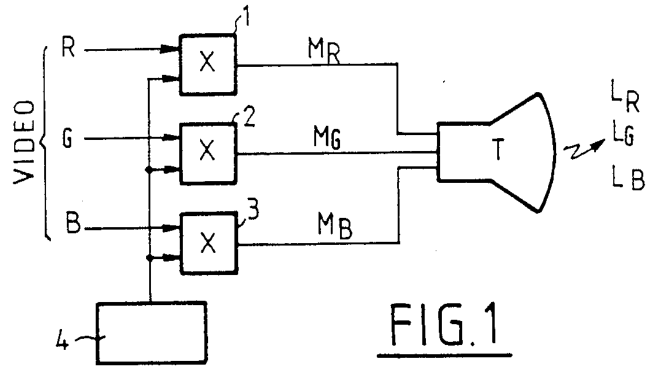


FIG.1

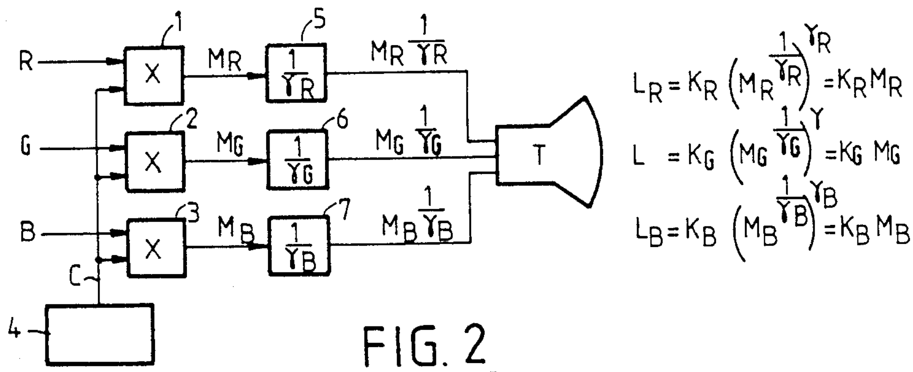


FIG. 2

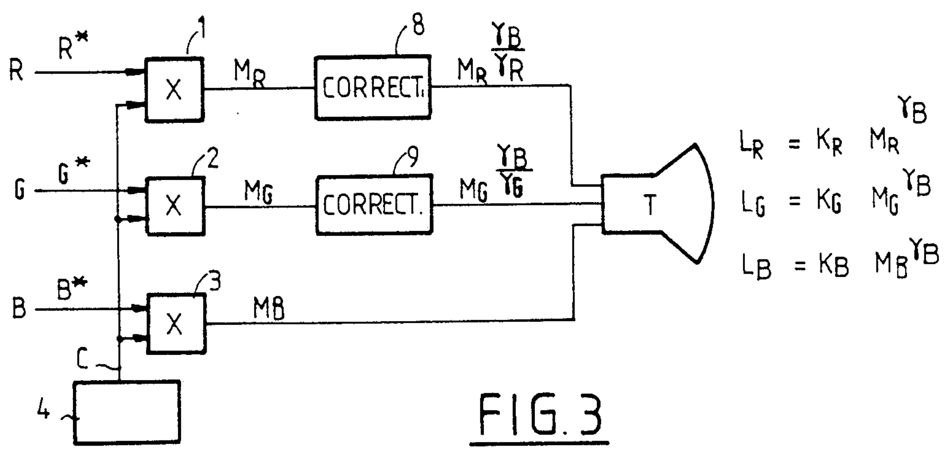


FIG.3

FIG. 4

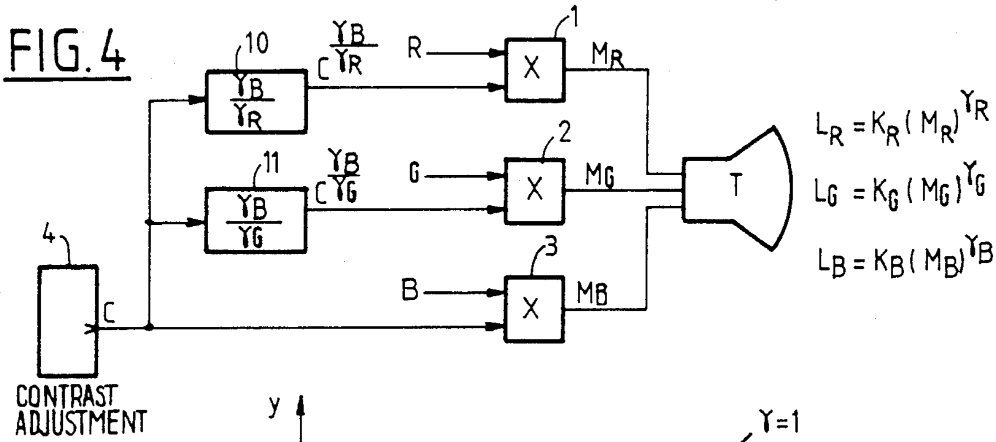


FIG. 5

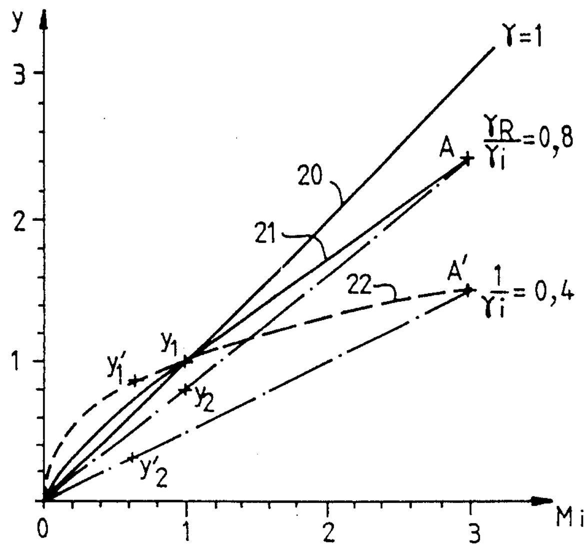


FIG. 6

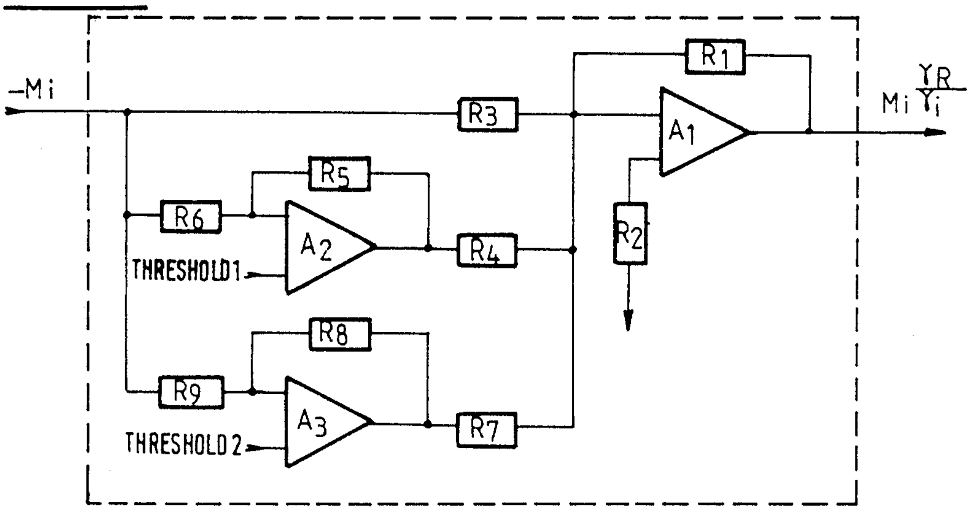
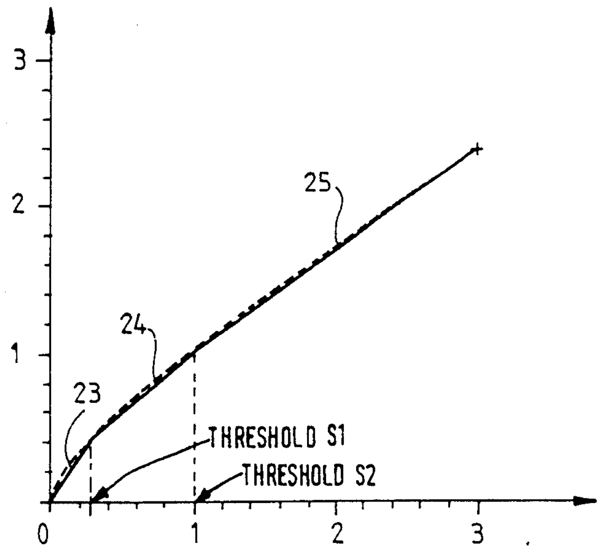


FIG. 7



METHOD AND DEVICE FOR GAMMA CORRECTION IN MULTICHROME CATHODE RAY TUBES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method and device for gamma correction in multichrome cathode ray tubes.

Its aim is more particularly to ensure conservation of the chromaticity of the colors displayed on the screen, over the whole dynamic range of adjustment of the contrast of the tube.

2. Description of the Prior Art

It is generally known that, in a conventional trichromatic cathode ray tube, the color picture points are each formed of three primary juxtaposed luminophore elements of red, green and blue color. These luminophore elements are excited by the flow of electrons from three electron guns assigned respectively to these three primary colors.

Such as seen by an observer, the color of this image point then consists in the additive synthesis of these three primary colors and depends on the relative proportions of the luminances L_R, L_G, L_B of these elements.

Now, the luminances generated by the three guns have as expression:

$$L_R = K_R(M_R)^{\gamma R} \text{ (red gun)}$$

$$L_G = K_G(M_V)^{\gamma G} \text{ (green gun)}$$

$$L_B = K_B(M_B)^{\gamma B} \text{ (blue gun)}$$

in which expressions, for a color, R, G, B shown in subscript:

the term M represents the cathode modulation;

the term γ represents the gamma exponent (between 2 and 3);

the term K is a constant.

It proves then that the transfer function $L=f(M)$ is different for each gun.

Furthermore, the contrast control acts simultaneously on the modulation of the three video channels, so that when this control varies the relative proportions of the luminances are modified because of the differences between the transfer functions of the guns. A variation of the chromaticity may then be observed depending on the contrast adjustment.

This drawback is particularly important in numerous applications which require considerable contrast variations and in which the colors form part of a symbology and have very precise meanings. Such is the case particularly in aeronautics.

For overcoming these disadvantages it has been proposed to introduce a correction (gamma correction) of type $1/\gamma_i$ in each video channel so as to linearize the transfer curves $L=f(M)$ of each of the guns.

However, this method comprises the following limitations:

the correction circuits placed directly in the video channels must have a wide pass band;

the high correction amplitude $(M^{1/\gamma})$ requires use of expensive techniques for attaining the precision and stability required;

the luminance emitted by the tube is proportional to the contrast control; since perception of the eye is logarithmic, the result is a loss of sensitivity for the low levels; the video signals and the contrast control signal must therefore be compensated for accordingly;

in an assembly including a camera connected to the tube, the fact of linearizing the response of the tube impairs restitution of the grey levels from the camera whose transfer function (analysis gamma) is substantially the reverse of that of the uncorrected tube.

SUMMARY OF THE INVENTION

The purpose of the invention is therefore to overcome these drawbacks. It provides a gamma correction method for multichrome tubes which consists more particularly:

in taking as reference the transfer function $L_{ref} = K_{ref}(M_{ref})^{\gamma ref}$ relative to one of the guns of the tube, and

in applying to the other guns a differential correction so that the modulation M_i of these guns passes to a value $M_i^{\gamma_{ref}/\gamma_i}$ in which γ_i is the gamma exponent of the gun considered so as to make the transfer functions of these guns proportional to that of the gun taken as reference and so that consequently the ratio of the luminances remains constant whatever the control level of the contrast.

With this method, the correction to be made has a much smaller amplitude than the correction of type $1/\gamma_i$ usually adopted.

This correction may then be advantageously put into effect by creating a mathematical model of the correction curve by means of straight line segments which each correspond to a range of variation of the modulation signal, and by amplifying this signal with a gain depending on the slope of the corresponding straight line segment of the model of the curve created, the technique used for this purpose being that of a slope switching device.

It has proved that this solution is all the more efficient the lower the amplitude of the correction (a reduced number of slopes ensuring an excellent correction precision). It has the further advantage of being very stable with respect to the temperature.

Another advantage of the above described method consists in the fact that the correction to be made to the modulation M_i may be applied either directly in the video channel, or to the contrast control.

Of course, the invention also relates to gamma correction devices using the above defined method.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the invention will be clear from the embodiments described hereafter, given solely by way of non limitative examples, with reference to the accompanying drawings in which:

FIG. 1 shows schematically the video circuit generally equipping a trichrome cathode ray tube;

FIG. 2 is a diagram similar to that of FIG. 1, in which appear the gamma correction circuits usually used;

FIG. 3 illustrates, in a circuit similar to that of FIGS. 1 and 2, the principle of the method of the invention, in the case where the correction is made directly on the video signal;

FIG. 4 shows schematically another embodiment of the invention in which the correction is made on the contrast control;

FIG. 5 is a diagram illustrating the amplitude of the correction made in accordance with the method of the

invention and that relative to a conventional gamma correction;

FIG. 6 shows schematically a slope switching correction circuit; and

FIG. 7 is a diagram showing one method of creating a mathematical model of the correction curve by means of straight line segments.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The circuit shown in FIG. 1 includes conventionally three video lines R, G, B assigned to the three primary colors, namely red for line R, green for line G and blue for line B. These three lines R, G, B are connected respectively to the three electron guns of a trichrome electron tube T, through three circuits 1, 2, 3 adapted for causing a variation of contrast in response to the same control signal C coming from contrast adjustment device 4.

These circuits 1, 2, 3 deliver then electric modulation signals M_R, M_G, M_B which are transformed respectively by tube T into luminance light signals L_R, L_G and L_B having for expression:

$$L_R=K_R(M_R)^{\gamma R}$$

$$L_G=K_G(M_G)^{\gamma G}$$

$$L_B=K_B(M_B)^{\gamma B}$$

The conventional solution for providing gamma correction consists in using in each of the video lines a correction circuit 5, 6, 7 raising the modulation signals M_R, M_G and M_B respectively to the powers $1/\gamma_R$ $1/\gamma_G$ and $1/\gamma_B$ (FIG. 2).

The expressions of the luminances L_R, L_G and L_B then become:

$$L_R = K_R\left(M_R^{\frac{1}{\gamma R}}\right)^{\gamma R} = K_R M_R$$

$$L_G = K_G\left(M_G^{\frac{1}{\gamma G}}\right)^{\gamma G} = K_G M_G$$

$$L_B = K_B\left(M_B^{\frac{1}{\gamma B}}\right)^{\gamma B} = K_B M_B$$

Linearization of the transfer curves is obtained.

The drawbacks of this solution which have been outlined above, are suppressed using the correction method of the invention whose principle is illustrated by means of the circuits shown in FIGS. 3 and 4.

In the circuit shown in FIG. 3, the correction takes place in two of the three lines of the video channel, namely the lines R and G.

It consists in taking as reference the transfer function of one of the guns, here the blue gun, and in correcting the modulation M_R and M_G of the other guns by means of the correction circuits 8, 9, raising the modulation M_R to the power γ_B/γ_R and the modulation M_G to the power γ_B/γ_G.

The luminances obtained on the screen are then in the form:

$$L_R = K_R\left(M_R^{\frac{\gamma B}{\gamma R}}\right)^{\gamma R} = K_R M_R^{\gamma B}$$

$$L_G = K_G\left(M_G^{\frac{\gamma B}{\gamma G}}\right)^{\gamma G} = K_G M_G^{\gamma B}$$

$$L_B = K_B(M_B^{\gamma B})$$

In other words, the transfer functions of the R and G lines are referred to that of line B.

Consequently, the luminance ratios are conserved whatever the level of the contrast control. In fact, the relations between the modulation and the contrast control C may be expressed in the following way:

$$M_R=C\times R^*$$

$$M_G=C\times G^*$$

$$M_B=C\times B^*$$

In which expressions the terms R*, G* and B* represent respectively the information relative to the red, green and blue colors of lines R, G, B upstream of the circuit 1, 2 and 3.

The expressions of the luminances then become:

$$L_B=K_B(C\times B^*)^{\gamma B},$$

$$L_R=K_R(C\times R^*)^{\gamma B}, \text{ and}$$

$$L_G=K_G(C\times G^*)^{\gamma B}.$$

The ratio of the luminances L_B and L_R is then:

$$\frac{L_B}{L_R} = \frac{K_B}{K_R}\cdot\frac{(C\times B^*)^{\gamma B}}{(C\times R^*)^{\gamma B}}$$

It is clear that this ratio remains constant whatever the value of the control voltage c.

It is moreover apparent that, contrary to conventional gamma correction devices, a linear variation of the contrast control c is perceived linearly by the eye. In fact, the logarithmic perception of the eye is compensated for by the exponential response of the tube.

Furthermore, it should be noted that the signal delivered by a monochrome video camera is of the form:

$$V=k_aL_a^{\gamma a}$$

In which expression:

V is the voltage delivered,

L_a is the luminance received by the camera,

γ_a is the analysis gamma ($\simeq$0.4),

K_a is a constant.

The connection of this camera to a cathode ray tube through a video processing circuit including a correction circuit in accordance with the invention leads to obtaining a restored luminance L_{RES} of the form:

$$L_{RES}=K_{RES}k_aL_a^{\gamma a\gamma RES}$$

γ_{RES} is the gamma of the tube

K_{RES} is a constant.

Now, the luminance L_{RES} restored by the tube must be proportional to the luminance L_a analysed by the camera (correct restitution of the grey levels). This condition is fulfilled for $\gamma_{RES}=1/\gamma_a$.

In practice, the analysis gamma γ_a is the reverse of the gamma of a cathode ray tube; the condition is thus automatically fulfilled and may be applied by taking as reference gamma for the tube the reverse of the specified analysis gamma.

This condition is not obtained in the case of a conventional correction of type $1/\gamma_i$ aiming at linearizing the transfer functions of the tube. It is then necessary to precorrect separately the signal coming from the camera, which forms a relatively important disadvantage.

In the variant of construction shown in FIG. 4, the correction is no longer made in the video channel of the tube but in the contrast control circuit.

In this example, this correction is provided by two correction devices 10, 11 acting on the contrast control signal c between the contrast variation circuits 1, 2 and the contrast adjustment device 4.

The correction devices 10 and 11 cause the control signal c to be transformed into a signal of the form

$$c^{\frac{\gamma B}{\gamma R}}$$

for the contrast control associated with the red video line R and into a signal of the form

$$c^{\frac{\gamma B}{\gamma G}}$$

for the contrast control associated with the green video line G.

As before, luminance signals may be obtained having the following form:

$$L_B=K_B(C\times B^*)^{\gamma B}$$

$$L_R=K_R(C\times R^*)^{\gamma B}, \text{ and}$$

$$L_G=K_G(C\times G^*)^{\gamma B}$$

This solution has an additional advantage with respect to the preceding one. The correction circuits 10, 11 do not need to have a high pass band ($\simeq$ video) since they are placed in a slow control circuit.

In this type of application, the transfer function differs according to whether the input variable is the contrast control signal c or the video signals R, G, B.

Thus in the case where the input variable is the signal c with the signals R, G, B as parameters, the transfer function will be of the form:

$$L_i=K_i(M_i)^{\gamma REF}$$

γ_{REF} being the coefficient of the reference gun.

On the other hand, in the case where the input variables are the video signals R, G, B with signal c as parameter the transfer function will be of the form:

$$L_i=K_i(M_i)^{\gamma i}$$

γ_i being the γ coefficient of the gun considered.

Curves given in the diagram of FIG. 5 show that the amplitude Δy of the corrections carried out by the devices 8, 9, 10, 11 of the present invention remains very

much less than the amplitude of the conventional corrections of type $1/\gamma_i$.

These curves have been plotted for an example including:

a reference gamma exponent γ_R+2

a gamma exponent of one of the other guns $\gamma_i=2.5$

cathode modulation M_i (which corresponds to the "full on" of the tube) equal to $M_i=3$.

The diagram includes more particularly:

a curve 20 of the form $y=M_i$ (with a gamma equal to 1),

a curve 21 of the form

$$y = M_i^{\frac{\gamma ref}{\gamma i}}$$

which, by taking the above indicated values, becomes $y=M_i^{0.8}$,

a curve 22 of the form:

$$y = M_i^{\frac{1}{\gamma i}},$$

namely $y=M_i^{0.4}$.

In the case of curve 21, which corresponds to the solution proposed by the present invention, the correction Δy has a maximum amplitude when the drift of the function $y=M_i^{0.8}$ is equal to the slope of the straight line OA, point A having as coordinates:

$$\begin{cases} M_i = 3 \\ y = 3^{0.8} = 2.41. \end{cases}$$

The slope of the straight line OA is equal to

$$\frac{y}{M_i} = \frac{2.41}{3} = 0.8$$

and the drift of the function is written:

$$\frac{dy}{dM_i} = 0.8\ M_i^{-0.2}$$

The value of M_i corresponding to this maximum amplitude is divided therefrom:

$$0\ 8M_i^{-0.2}=0.8\rightarrow M_i=1$$

then the values y_1 and y_2 corresponding to this value of M_i on curve 21 and on the straight line OA,

$$y_1=M_i^{0.8}=1$$

$$y_2=0.8M_i=0.8$$

The maximum amplitude of the correction is then obtained by the difference:

$$y_1-y_2=\Delta_y=0.2$$

The maximum amplitude of the correction of type $1/\gamma_i$ (curve 22) is determined analogically, with:

the coordinates of point A' equal to

$$M_i=3 \text{ and } y'=3^{0.4}=1.55$$

the slope of segment OA' equal to

$$\frac{y'}{M_i} = 0.52$$

the drift

$$\frac{dy'}{dM_i} = 0.4\, M_i^{-0.6} = 0.52$$

the value of M_i corresponding to the maximum amplitude $M_i = 0.65$

the values y'_1 and y'_2:

$$y'_1 = 0.65^{0.4} = 0.84$$

$$y'_2 = 0.65 \times 0.52 = 0.34$$

Thus a maximum correction amplitude $y'_1 - y'_2 = 0.5$ is obtained. It is clear that this maximum amplitude is much greater than that obtained previously, namely:

$$y_1 - y_2 = 0.2.$$

With this feature, a switching device may be used for the correction having a slope such as the one shown in FIG. **6** and which comprises:

an amplifier-summator circuit including conventionally an operational amplifier **A1** and resistors **R1** and **R2** the input of this amplifier receiving the signal $-M_i$ through:

a resistor R_3,

a first threshold device (of threshold S_1) including the operational amplifier A_2 and the resistors R_4, R_5, R_6, and

a second threshold device (of threshold S_2 greater than S_1) including the operational amplifier A_3 and the resistors R_7, R_8, R_9.

This correction device therefore allows a mathematical model to be created of the correction curve in three straight line sections such as shown in FIG. **7**, namely:

a first straight line segment **23** included between point O and the value of M_i corresponding to the threshold S_1 of the first threshold device, the slope of this segment corresponding to the gain of the amplifier circuit A_1, R_1, R_2, R_3;

a second straight line segment **24** included between the values of M_i corresponding to the thresholds S_1 and S_2 of the two threshold devices, the slope of this second segment corresponding to the sum of the gains of the amplifier circuit A_1, R_1, R_2, R_3 and of the first threshold device; and

a third straight line segment **25** included between the value of M_i corresponding to the threshold S_2 and the value of M_i corresponding to the point A such as previously defined, the slope of this third segment corresponding to the sum of the gains of the amplifier circuit and of the two threshold devices.

The principle of this correction device is therefore particularly simple. Although a mathematical model may be created of the correction curve using a very reduced number of segments, an excellent precision of correction is however obtained. This device has the further advantage of being very stable with respect to the temperature.

What is claimed is:

1. A gamma correction method for multichrome cathode ray tubes equipped with a contrast control circuit acting simultaneously on the cathode modulation signals of the electron guns of the tube, comprising:

taking as reference the transfer function $L_{ref} = K_{ref}(M_{ref})^{\gamma ref}$ relative to one of the guns of the tube, L_{ref} being the luminance generated by the reference gun, M_{ref} being the modulation applied to the cathode of the reference gun, K_{ref} being representative of a constant and the term γ_{ref} representing the gamma exponent of the reference gun, and

applying to the other guns a differential correction causing the cathode modulation M_i of these other guns to pass to a value $M_i\ \gamma_{ref}/\gamma_i$ in which the exponent γ_i is the gamma exponent of the gun considered so as to make the transfer functions of said other guns proportional to that of the gun taken as reference, and so that consequently the ratio of the luminances remains constant whatever the contrast control level of the tube.

2. The method as claimed in claim **1**, wherein said correction is carried out by creating, with straight line segments, a mathematical model of a correction curve defined by a relation $y = M_i\gamma_{ref}/\gamma_i$ y representing the amplitude of the correction.

3. The method as claimed in claim **1**, which comprises the step of applying said correction in the video channel, to the cathode modulation signals of the electron guns.

4. The method as claimed in claim **1**, which comprises the step of applying said correction to the contrast control.

5. The method as claimed in claim **1**, wherein said correction includes for each of the electron guns considered the steps of:

determining the curve of correction to be made to the cathode modulation signal of this gun,

creating a mathematical model of this correction curve by means of straight line segments which each correspond to a range of variation of the modulation signal,

amplifying the modulation signal in each of said ranges with a gain depending on the slope of the corresponding straight line segment of the model curve.

6. A device for effecting a gamma correction for a multichrome cathode ray tube provided with n electrode guns, said device comprising for each of the $n-1$ electron guns of the tube a correction circuit adapted for raising the cathode modulation of this gun to a power γ_{ref}/γ_i, in which the term γ_{ref} is the gamma exponent of the nth gun which is taken as reference and the term γ_i is the gamma exponent of the gun considered.

7. The device as claimed in claim **6**, wherein said correction circuits are disposed in the red and green video circuits connecting the contrast variation circuits to the $n-1$ corresponding electron guns.

8. The device as claimed in claim **6** wherein said correction circuits are disposed in the circuits connecting the contrast adjustment device to the contrast variation circuits assigned to said $n-1$ guns.

9. The device as claimed in claim **6**, wherein said correction circuit consists of slope switching circuit.

10. The device as claimed in claim **6**, wherein said correction circuit includes an amplifier-summator circuit receiving the signal to be corrected directly and through at least one threshold device.

* * * * *

RÉPUBLIQUE FRANÇAISE

INSTITUT NATIONAL
DE LA PROPRIÉTÉ INDUSTRIELLE

PARIS

(11) N° de publication : **2 312 150**
(A n'utiliser que pour les commandes de reproduction).

A1

DEMANDE DE BREVET D'INVENTION

(21) **N° 75 16065**

(54) **Dispositif de correction de gamma et caméra de télévision et télécinéma incluant un tel dispositif.**

(51) Classification internationale (Int. Cl.²). **H 04 N 5/14.**

(22) Date de dépôt .... 23 mai 1975, à 11 h 26 mn.

(33) (32) (31) Priorité revendiquée :

(41) Date de la mise à la disposition du public de la demande .... B.O.P.I. — «Listes» n. 51 du 17-12-1976.

(71) Déposant : Société dite : THOMSON-CSF, résidant en France.

(72) Invention de :

(73) Titulaire : *Idem* (71)

(74) Mandataire :

D Vente des fascicules à l'IMPRIMERIE NATIONALE, 27, rue de la Convention — 75732 PARIS *CEDEX 15*

Il est bien connu aujourd'hui que, moins encore que le cinéma, la télévision n'est capable de reproduire intégralement la gamme des contrastes rencontrés habituellement dans la nature.

Ceci provient, en premier lieu, de la difficulté d'obtenir des brillances très élevées sur les écrans de télévision. Les limitations sont dues ici à la dissipation maximale tolérable sur l'écran d'un tube cathodique, à l'écrasement du spot et au rendement de la substance luminescente.

Du côté des faibles brillances, les limitations proviennent des réflexions internes du tube cathodique et surtout de la très forte lumière parasite inondant l'écran chez la plupart des télé-spectateurs. Des efforts considérables ont été faits pour améliorer cet état de chose ; dalles teintées dans la masse pour réduire le rapport entre lumière réfléchie et lumière émise, conseils divers pour placer des lumières d'ambiance derrière l'écran et non devant etc ...

Le résultat final reste médiocre et on peut constater généralement que le contraste réel au cinéma atteint un rapport de 80 alors qu'en télévision, il ne dépasse pas 50.

Or le contraste rencontré dans les scènes d'extérieur ou de studio dépasse souvent 100 et quelquefois 1000.

Une solution connue consiste à décaler le niveau du noir à chaque image tout en maintenant une correction de gamma fixe sur la chaîne d'amplification du signal video ou des signaux video.

Cette solution est insuffisante : dans le cas par exemple d'une image prise dans la brume, on n'augmentera le contraste que dans les parties les plus sombres alors que l'ensemble de l'image est plat.

On a également proposé l'utilisation de correcteurs de gamma variables commandés manuellement par l'opérateur en fonction du contraste général de la scène.

Cette solution, outre qu'elle est astreignante, présente un caractère subjectif et des temps de réponse de l'opérateur à un changement de scène qui ne sont évidemment pas négligeables.

La présente invention a pour objet un dispositif de correction de gamma dans lequel le gamma varie automatiquement en fonction du contraste de la scène. Elle a également pour objet les caméras de télévision et télécinémas utilisant un tel dispositif.

L'invention sera mieux comprise et d'autres caractéristiques apparaîtront à l'aide de la description ci-après et des dessins s'y rapportant sur lesquels :

- la figure 1 illustre un mode de réalisation du dispositif suivant l'invention pour une prise de vue de télévision monochrome ;
- la figure 2 donne un mode de réalisation du dispositif suivant l'invention pour une prise de vue de télévision en couleur ;
- la figure 3 donne un mode de réalisation du dispositif suivant l'invention convenant pour un télécinéma.

Sur la figure 1 , l'entrée E fournit le signal de sortie d'une caméra de télévision noir et blanc.

Ce signal passe dans un premier circuit d'alignement (opération dite "clamping" en anglais) 1 , recevant les impulsions d'alignement à fréquence de ligne d'une entrée 19, suivi, en parallèle, d'un amplificateur à gain variable 2 et d'un détecteur de crête 3 , à diode, résistance et capacité, dont le signal de sortie est relié à l'entrée de commande de gain de l'amplificateur 2 dont le rôle est de ramener à l'intervalle normalisé "0-1" la dynamique de son signal d'entrée, le niveau 1 correspondant aux crêtes. Suivant l'art connu, la constante de temps T_1 du détecteur 3 est voisine de la durée de trois ou quatre trames. Un second circuit d'alignement 4 , recevant les mêmes impulsions que le premier, rétablit si nécessaire le niveau 0 correct.

Le signal de sortie du circuit 4 est appliqué à l'entrée d'un correcteur de gamma variable 5.

Cette partie du circuit est connue en elle-même.

Mais le correcteur de gamma 5 doit d'une part être choisi à variation continue, et d'autre part son entrée de commande 6 doit être une entrée électrique, telle qu'utilisée par exemple pour une commande manuelle à distance. L'intervalle de variation de la valeur de gamma sera avantageusement l'intervalle classique de 0,3 à 0,6 , centré sur la valeur 0,45 (inverse du gamma 2,2 des tubes récepteurs). On peut utiliser par exemple un correcteur variable classique comportant, en parallèle, deux correcteurs fixes, impartissant respectivement des gammas de 0,3 et 0,6, et alimentant un mélangeur mélangeant leurs signaux de sortie en proportion variable sur la commande d'une tension continue variable.

Suivant l'invention, l'entrée de commande 8 est reliée à la sortie d'un détecteur de valeur moyenne . Celui-ci est constitué par un filtre passe-bas, suivi d'un détecteur de crêtes, le filtre passe-bas comportant une résistance d'entrée 50 dont la première borne est reliée à la sortie du circuit d'alignement 4 , et dont la seconde borne 51 est reliée à une borne d'un condensateur 52 dont l'autre borne est à la masse. Le détecteur de crête comporte une diode 53 dont l'anode est reliée à la borne 51 , et dont la cathode est reliée à la masse par un condensateur 54 en parallèle avec une résistance 55. La sortie (cathode de la diode) du détecteur de valeur moyenne est reliée à l'entrée de commande 8 du correcteur de gamma.

La constante de temps du détecteur de valeur moyenne, déterminée à la fois par celle du circuit R-C 50-52 constituant le filtre passe-bas et celle du détecteur de crêtes 53 , 54 , 55 , est prise inférieure à celle du détecteur de crêtes 3 , par exemple égale à la durée d'une trame à une trame et demie.

La constante de temps T_2 du détecteur de valeur moyenne peut en effet être très courte (à peine supérieure à une trame) car l'énergie maximale du signal video est concentrée dans les fréquences basses et l'impédance interne de la source peut être relativement plus basse que pour le détecteur de crêtes.

D'autre part, le temps de mesure des écarts de valeur moyenne est plus court que celui de la valeur de crête à cause de l'action déjà très efficace du détecteur de crête 3 sur le maintien du niveau à l'entrée du détecteur de valeur moyenne.

La constante de temps totale pour les deux corrections (dynamique et gamma) peut être considérée comme approximativement égale à la somme des constantes de temps du détecteur de crête et du détecteur de valeur moyenne.

La figure 2 montre un dispositif correspondant pour une caméra de signaux de télévision en couleur.

Les 3 entrées E_1 , E_2 et E_3 reçoivent les signaux R (rouge), G (vert) et B (bleu) alimentant respectivement trois chaînes identiques à la chaîne 1 , 2 , 4 , 5 du circuit de la figure 1 , et dont les éléments sont repérés par des nombres augmentés respectivement de 10 , 20 et 30 par rapport à la figure 1.

Un détecteur de crête est commun aux trois chaînes. Il comporte trois diodes 61 , 62 et 63 dont les anodes sont respective-

ment reliées aux sorties des circuits d'alignement 11 , 21 et 31 et dont les cathodes sont reliées à une borne commune 66 , un condensateur 64 et une résistance 65 étant montés en parallèle entre la borne 66 et la masse.

La sortie (borne 66) du détecteur de crête est reliée aux entrées de commande de gain des trois amplificateurs 12 , 22 et 32.

Les sorties des circuits d'alignement 14 , 24 et 34 sont reliées aux trois entrées d'une matrice 70 formant le signal de luminance, et la sortie de la matrice est reliée à l'entrée d'un détecteur de valeur moyenne 6 identique au détecteur de valeur moyenne de la figure 1 , et dont la sortie est reliée aux entrées de commande des correcteurs de gamma 15 , 25 et 35.

Les constantes de temps peuvent être les mêmes que pour le circuit de la figure 1.

Les montages précédents conviennent pour la prise de vue directe d'une scène, étant donné qu'un cadreur, normalement, ne fait pas subir de très brusques changements d'orientation à sa caméra. Il suffira que la transmission des signaux à l'antenne ne débute qu'après un intervalle de temps égal à la durée de quatre ou cinq trames après la mise en oeuvre du dispositif.

Le cas est différent dans un télécinéma où l'on saute souvent brusquement d'une scène à une autre. Dans ce dernier cas, il est préférable de prévoir une "pré-analyse" de la brillance des images du film précédant l'analyse ponctuelle de télévision afin que la correction de gamma soit commandée avec un meilleur synchronisme que dans le cas de la prise de vues directes. Cette pré-analyse n'a pas besoin d'avoir la même finesse que l'analyse télévisuelle.

La figure 3 illustre un dispositif correspondant. L'entrée E reçoit le signal résultant de l'analyse télévisuelle du film.

Le montage comporte des éléments identiques à ceux de la figure 1 , et repérés par les mêmes nombres, excepté que le détecteur de valeur moyenne est représenté globalement par un bloc 6. Ces éléments sont montés de la même manière que sur la figure 1 excepté que le détecteur de crête 3 n'est pas alimenté par les signaux résultant de l'analyse télévisuelle , mais par la sortie d'un dispositif de pré-analyse du film placé en amont de la fenêtre d'analyse télévisuelle. On supposera T_1 égal à la durée de quatre trames, T_2 égal à la durée de une trame à une trame et demie.

Sur la figure, le film 80, avant de passer dans la fenêtre d'analyse télévisuelle , défile, maintenu sur ses bords par un support non représenté, devant une barrette 81 de photodiodes, éclairées, au travers de la partie impressionnée du film et d'un objectif 85, par un tube d'éclairage 82. La sortie de la barrette 81, est reliée à l'entrée du détecteur de crête 3.

Les photodiodes répondent au même spectre que les détecteurs utilisés dans l'analyse télévisuelle compte tenu des filtres optiques éventuellement insérés dans le dispositif de pré-analyse et le dispositif d'analyse télévisuelle.

La barrette de photodiodes est d'un type connu comportant un alignement de 256 diodes commandées, pour la lecture, au moyen d'un registre à décalage. L'objectif 85 permet d'amener à égalité la longueur d'une ligne d'image et celle de l'alignement de photodiodes.

Dans le sens de la hauteur de l'image, un ajustement critique n'est pas nécessaire et les photodiodes peuvent par exemple, pour chaque analyse horizontale, couvrir une hauteur d'image d'un ordre de grandeur de celle de une à deux lignes d'image.

La pré-analyse s'opère naturellement sans entrelacés.

Chaque impulsion à fréquence de ligne fournie sur l'entrée 19 est utilisée d'une part pour placer dans l'état 1 le premier étage du registre à décalage, et d'autre part pour déclencher un oscillateur 86 fournissant pour chacune d'elles un train d'impulsions rapides, chaque train comportant au moins 256 impulsions, qui sont appliquées à l'entrée d'horloge du registre, de manière que chaque photodiode de l'alignement soit successivement interrogée.

La cadence d'analyse horizontale est dans cet exemple la fréquence de ligne, soit 15,625 kHz dans les normes européennes à 625 lignes.

Mais cette cadence n'est pas impérative. On peut par exemple la réduire en vue de gagner en sensibilité.

Compte tenu de ce que chaque image du film n'est analysée qu'une fois, par une trame impaire et une trame paire, dans le dispositif d'analyse télévisuelle, et des temps de réponse des détecteurs, la barrette de diodes devra être située à un emplacement tel que la pré-analyse porte sur la $(n+p)^e$ image du film lorsque la n^e image sera analysée dans le dispositif d'analyse télévisuelle, p est dans

cet exemple tel que l'analyse télévisuelle d'une image du film s'opère, par rapport à sa pré-analyse avec un retard égal à la constante de temps T_1 du détecteur de crêtes, soit p = 2 . On peut également tenir compte de la constante de temps T_2 , plus courte, du détecteur de valeur moyenne, et prendre un retard égal à $T_1 + T_2$ ou à une valeur intermédiaire entre T_1 et $T_1 + T_2$.

Compte tenu des figures 2 et 3 , la structure du dispositif de correction de gamma pour un télécinéma en couleur est immédiate. Le dispositif sera constitué comme le dispositif de la figure 2 sauf en ce qui concerne l'alimentation du détecteur de crête ; cette alimentation s'effectue au moyen d'une pré-analyse utilisant trois barrettes de photodiodes respectivement sensibles (compte-tenu de filtres optiques les précédant) aux mêmes raies spectrales que celles qui sont fournies par les filtres optiques rouge, bleu et vert utilisés dans l'analyse ponctuelle, les sorties des trois barrettes alimentant respectivement les trois diodes du détecteur de crête.

On peut par exemple éclairer simultanément les trois barrettes au travers de la même partie du film, par l'intermédiaire de l'objectif et d'un système de miroirs dichroïques.

REVENDICATIONS

1. Dispositif de correction de gamma de n signaux video de télévision (n = 1 pour la télévision monochrome, n = 3 pour la télévision en couleur) représentatif d'une scène, comportant n correcteurs de gamma variables pouvant être commandés par un signal électrique, caractérisé en ce qu'il comporte un détecteur de la valeur moyenne de la luminance de la scène traduite par lesdits n signaux, la sortie dudit détecteur de valeur moyenne étant couplée aux entrées des n correcteurs de gamma variables.

2. Dispositif de correction de gamma suivant la revendication 1 , caractérisé en ce que la constante de temps T_2 dudit détecteur de la valeur moyenne de la luminance est notablement inférieure à la constante de temps T_1 du détecteur de crêtes régularisant la dynamique desdits n signaux video.

3. Dispositif de correction de gamma suivant la revendication 2 , caractérisé en ce que T_2 est compris entre la durée d'une trame et d'une trame et demie pour T_1 égal à la durée de trois ou quatre trames.

4. Dispositif de correction de gamma suivant l'une des revendications précédentes, caractérisé en ce que ledit détecteur de la valeur moyenne de la luminance est constitué par un filtre passe-bas suivi d'un détecteur de crête.

5. Dispositif de correction de gamma suivant l'une des revendications précédentes, avec n = 1 , caractérisé en ce que le détecteur de la valeur moyenne de la luminance est alimenté par le signal video à corriger en gamma.

6. Dispositif de correction de gamma suivant l'une des revendications 1 à 4 , avec n = 3 , caractérisé en ce que le détecteur de la valeur moyenne de la luminance est alimenté par une matrice de luminance recevant les signaux video à corriger en gamma.

7. Dispositif de correction de gamma suivant l'une des revendications précédentes, adapté à un télécinéma, caractérisé en ce qu'il comporte un dispositif de pré-analyse de la luminance du

film placé de manière à opérer cette analyse pour une image du film antérieurement à l'analyse de télévision de cette même image, et en ce que les n correcteurs de gamma sont alimentés par n amplificateurs variables commandés par le signal de sortie d'un détecteur de crêtes alimenté par le dispositif de pré-analyse.

8. Dispositif de correction de gamma suivant l'ensemble des revendications 5 et 7, caractérisé en ce que ledit dispositif de pré-analyse de la luminance comporte une barrette de photodiodes éclairée au travers du film, la sortie de la barrette constituant la sortie unique du dispositif de pré-analyse.

9. Dispositif de correction de gamma suivant l'ensemble des revendications 6 et 7, caractérisé en ce que leur dispositif de pré-analyse de la luminance comporte trois barrettes de photodiodes éclairées au travers du film, et répondant respectivement aux mêmes radiations que les détecteurs photosensibles utilisés dans l'analyse télévisuelle, et une matrice de luminance alimentée par les sorties de trois amplificateurs variables commandés par le signal de sortie d'un détecteur de crêtes alimenté par les signaux de sortie des trois barrettes.

10. Dispositif de correction de gamma suivant l'une des revendications 7, 8 ou 9, caractérisé en ce que ledit dispositif de pré-analyse du film est placé de manière que l'intervalle de temps séparant la pré-analyse d'une image du film de son analyse télévisuelle soit compris dans l'intervalle de durées T_1 à $T_1 + T_2$, T_1 étant la constante de temps du détecteur de crêtes et T_2 celle du détecteur de la valeur moyenne de la luminance.

11. Caméra de télévision munie d'un dispositif de correction de gamma suivant l'une des revendications 1, 2, 3 et 4.

12. Télécinéma muni d'un dispositif de correction de gamma suivant l'une des revendications 1 à 7.

FIG. 1

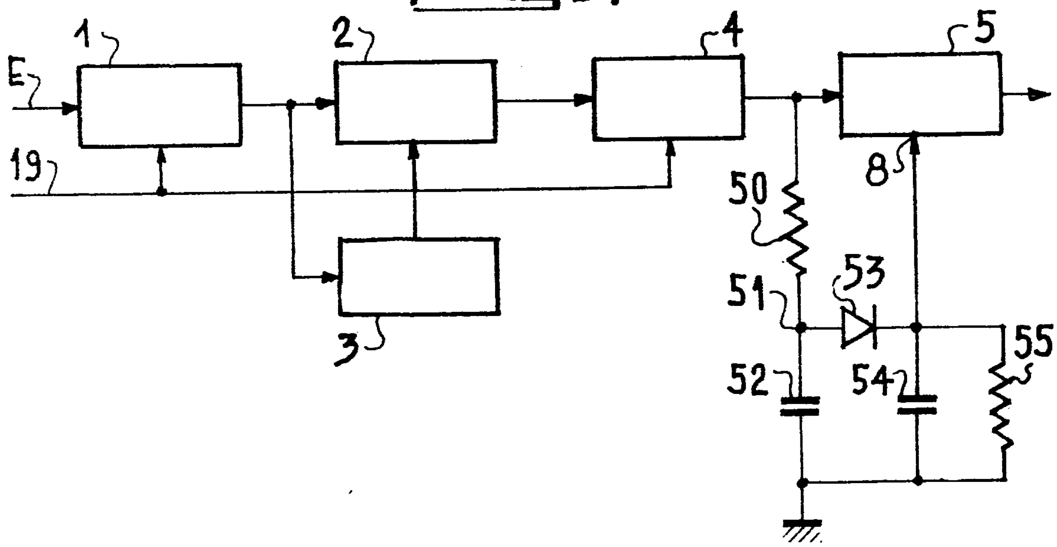
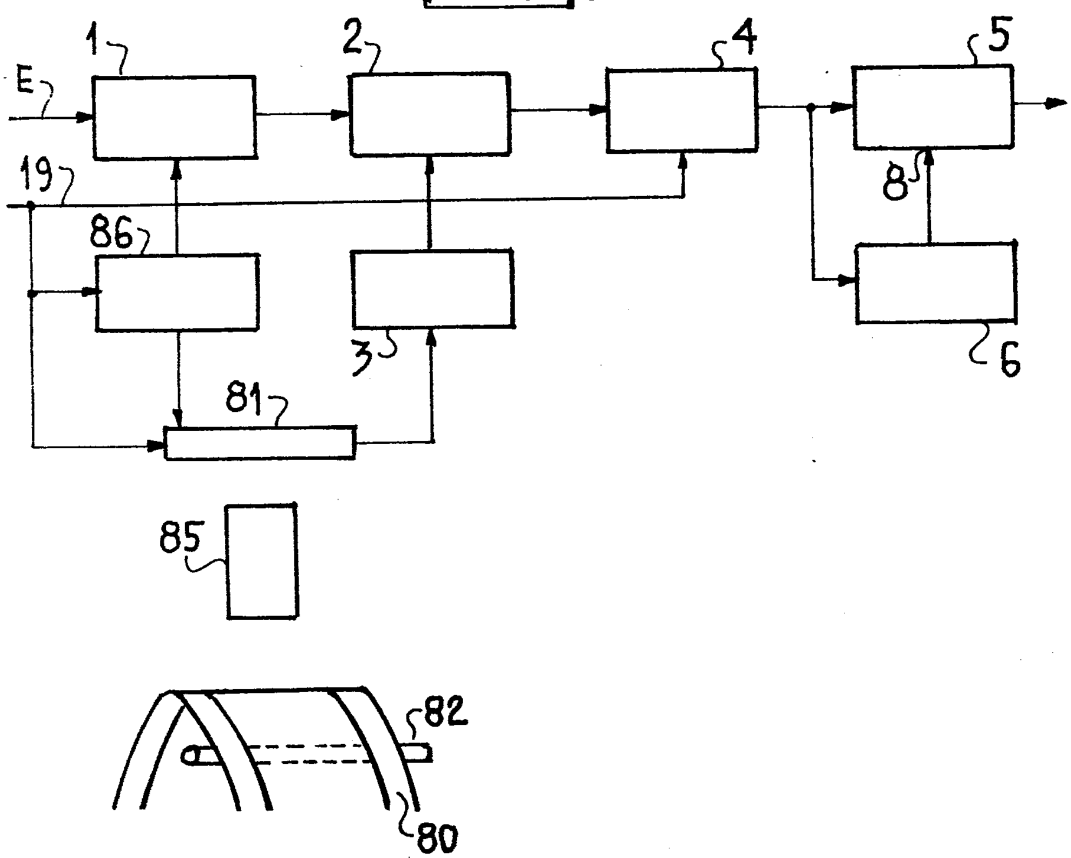
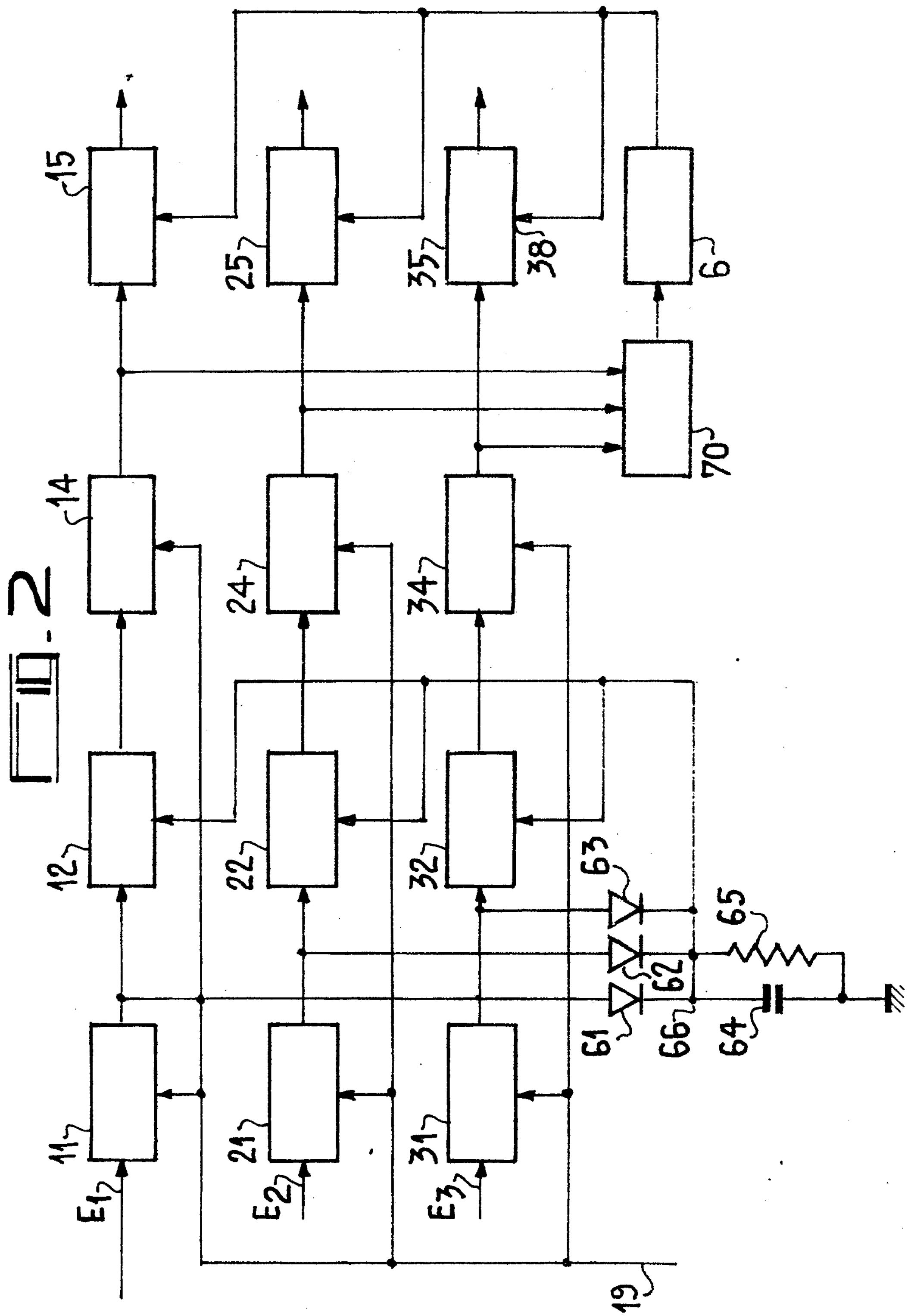


FIG. 3



PL. II-2 2312150



PATENT SPECIFICATION

(11) 1 605 009

(21) Application No. 53350/73 (22) Filed 16 Nov. 1973

(23) Complete Specification Filed 31 Jan. 1975

(44) Complete Specification Published 16 Dec. 1981

(51) INT. CL.[3] G01S 3/78

(52) Index at Acceptance
H4D 746 761 773 774 781

(72) Inventors: JACQUES AUGUSTIN GABRIEL HALÉ
JOHN JACKSON

1 605 009

(19) THE PATENT OFFICE LONDON

(54) OBJECT DETECTION APPARATUS

(71) We, MULLARD LIMITED, Abacus House, 33 Gutter Lane, London, E.C.2. a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to apparatus for processing pictures of scenes to detect small objects within such pictures. In addition to detecting small separate objects, small characteristic features of larger objects, such as corners, may also be detected. An indication that an object has been detected may be superposed on a visual version of the scene to aid human interpretation of the picture.

The objects may be detected by examination of the scene at another wavelength, for example, by emitted thermal radiation. Signals from a thermal detector scanning the scene may be converted to visual form and superposed in registration with a visual version of the objects to call the attention of a human observer to an object which is thermally emissive. An apparatus for conducting such a thermal examination of a scene and for superposing the results on a visual version of the scene will be defined herein as a thermal pointer.

Much of the information in the picture, which may be a visual version of the scene or a visible form of a thermal version of the scene, may be irrelevant but a small proportion of the information may be very important. It is then desirable to have a method of detecting objects of predetermined outline which has a high probability of object detection with an acceptably low false alarm rate.

The thermal detector provides a continuous analogue signal as it scans across the scene. The thermal detector signal may be sampled at discrete intervals of time or of distance in the scan and so dissect the scene into picture elements. The thermal detector output may be digitized and be represented by the closest member of a predetermined set of voltage levels representing corresponding brightness levels, for example 32 levels, and a 5 bit code representing the level is then used subsequently in the signal processing equipment. A defined range of voltage levels of the thermal detector signal will be referred to herein as a temperature window. Binarized picture elements, where only 'O' and 'I' are the picture element values, are not considered relevant herein.

The invention provides pictures processing apparatus for application to a picture comprising a regular two-dimensional array of picture elements each of which is the centre picture element of a plurality of radiating straight lines of contiguous picture elements aligned in radial directions and in which each picture element has a brightness value, said apparatus comprising means for determining the average brightness of one or more picture elements in such a radial direction, said average being taken over a number of picture elements small compared to the number of picture elements in the maximum dimension of the picture and excluding the said centre picture element, and means for providing an output signal when the said average brightness differs from the said centre picture element brightness by at least a predetermined threshold amount of the same sign on at least half of the said radial directions.

The said regular two-dimensional array may comprise regularly spaced rows and regularly spaced transverse columns of picture elements and the outermost picture element used for determining said average brightness in each radial direction may be contained within and be at the boundary of a rectangular array of picture elements having its sides parallel to said rows and columns respectively.

The said rectangular array of picture elements with associated signal processing apparatus will be referred to herein as an object detection operator or more simply, as an operator. It is referred to as an operator as it defines the set of picture elements involved in the operation of assessing the centre picture element brightness in relation to that of surrounding picture elements to detect an object.

The invention provides means for processing the information from the thermal detector of a thermal pointer before superposition on the visual version of the scene so as to preferentially detect those features in the scene which are man-made targets.

The purpose of using such a pointer with the invention is to find possible targets in difficult situations. Considerations of the sensitivity and range required in these limit situations are such that the image size of a detected object is only one to three times the size of the photocell. With so little information, it may then be difficult to decide on the identity of the object. This task is then left to the human observer who looks at the visible scene.

Generally, it may be said that to detect "targets' in a given signal (temporal or pictorial) is to find some characteristic sequence of events in a series of measurements on that signal. The events not subsequently identified as targets are considered to be "noise".

The present invention although oriented towards the design of a specific system, is basically concerned with the same problems as are other target location equipments such as radar alert systems, aerialphotograph processors, star locked navigation, etc. These problems have received, and still do receive, considerable attention from scientists and engineers.

Usually a gain control is provided in the apparatus so that a similar signal is obtained from objects of large temperature difference in a highly varying scene as is obtained from objects of small temperature difference in flat scenes. Since highly varying scenes are viewed with large temperature windows it is convenient to consider the picture element brightness or temperatures in terms of quantized levels of the temperature window instead of absolute temperature units.

An example of the object detection operator provided by the invention may be considered to be built up from four segments each segment being typically five points long and oriented along one of the four principal radial directions, two orthogonal and two diagonal, in the plane of the picture as shown in Figure 2b of the accompanying drawings. Each segment can be considered as a different filter. Only if the distribution of brightness along a segment meets a given criterion is the output of this segment "true". The overall response of the object detection operator is "true" and hence an object detected if each of the four segments gives a "true" output. The criterion for each radial direction is, as given hereinbefore, that the average brightness of the picture elements in a given radial direction, excluding the centre picture element, differs from the brightness of the centre picture element by at least a predetermined threshold amount. The difference in brightness may be of either sign. The operator may be used to detect cold objects against a warm background as well as warm objects against a cold background. The detector operates upon local differences of brightness or temperature in the scene and not on absolute brightnesses. The number of picture elements in a radial segment or direction, excluding the centre picture element, may be reduced to one in which case the average brightness reduces to the brightness of that one picture element.

Embodiments of the invention, given by way of example, will first be described in general terms with reference to Figures 1 to 4 of the accompanying drawings in which:-

Figure 1 shows a computer print-up of a portion of an infra-red scene.

Figure 2 shows the four segments of a 5×5 object detection operator,

Figure 3 shows a schematic drawing of an asymmetrical 5×5 object detection operator, and

Figure 4 shows the reduced corner detector (2 × 3).

Further more detailed embodiments will be described with reference to Figures 5-9 and Figures 10-12 respectively.

Referring to Figure 1, a computer print-up of a portion of an infra-red scene is shown. The original terrain was scanned by an infra-red detector and the radiance of the scene recorded in 100 lines of 200 points or picture elements each. The radiance of each point was recorded digitally as one of 32 levels, the whole range of levels representing a predetermined temperature range or 'window' in the scene. Figure 1 shows a portion of such a scene having 21 lines of 17 points each, the digitised value of radiance from 0 to 31 being shown at each point. Thus a rectangular array of picture elements and their brightnesses is obtained.

Referring to Figure 2(a) the notation used for the picture elements surrounding a centre picture element A and comprising the operative area of the object detection operator is shown. The centre picture element is taken as a local origin of co-ordinates, positive and negative whole number ordinates and abscissae being shown. Referring to Figure 2 (b) four

directions d are shown numbered and in any one direction d the positive and negative "radius" values k are shown.

An embodiment of the present invention, which can be implemented with the circuits described later with reference to Figures 10, 11 and 12, provides an object detection operator for small objects and is described in the following way.

For each direction d, two quantities are computed i.e.

$$L_{1d} = \tfrac{1}{2} \sum_{0}^{+2} a_k\, p(k) \text{ and}$$

$$L_{2d} = \tfrac{1}{2} \sum_{-2}^{0} a_k\, p\,(k)$$

p (k) being the brightness of the kth picture element in each direction and a_k being a constant which depends only on the modulus of k and

$$a_k = -1 \text{ for } k \neq 0$$

$$\text{and } a_k = 2 \text{ for } k = 0.$$

and where k is a whole number function used to describe the position of the picture elements along direction d (see Figure 2), and typically will have values between +2 −2, hence defining an object detection operator which is square and has five picture elements in a side. The condition of detection, R, of a small object becomes:-

$$R = 1 \text{ if } L_{1d} \text{ and } L_{2d} \geqslant T \text{ for } d = 1 \text{ to } 4 \text{ inclusive}$$

$$R = 0 \text{ otherwise, } T \text{ being a threshold value.}$$

In other words, to be accepted as belonging to a small object, a point must possess a brightness which exceeds by T the mean of the two neighbours on each of the eight vectors starting from this point.

The logical conditions can be changed in order to detect hot as well as cold objects, i.e.

$$R = 1 \text{ if } |L_{1d}| - T \geqslant 0 \quad \text{for } d = 1 \text{ to } 4 \text{ inclusive}$$

$$\text{and if } \quad |L_{2d}| - T \geqslant 0$$

$$R = 0 \text{ otherwise}$$

Another embodiment of the invention, which can also be implemented with the circuits described with reference to Figures 10, 11 and 12, provides an object detection operator for detecting 3 corners and small objects and can be described in a way similar to the small object detection operator. The condition of detection is:

$$R = 1 \text{ if } (L_{1d} - T) \geqslant 0 \quad \text{for } d = 1 \text{ to } 4 \text{ inclusive}$$

$$\text{or if } (L_{2d} - T) \geqslant 0$$

$$R = 0 \text{ otherwise}$$

In other words, for detection the centre point brightness must exceed by a threshold T the mean of that of the pairs of points along at least all those radial directions having the same

sign of k. This operator can detect corners of uniform objects of any size. If the size of the object is 2 × 2 then the four corners merge into a packed quadruple.

If the condition of detection is modified so that the absolute values of L_{1d} and L_{2d} are considered, then the detector will detect hot as well as cold objects.

Referring to Figure 3, an asymmetrical operator is shown in which the centre picture element is a picture element adjacent, along a row, to the centre of the 5 × 5 square of picture elements. Not all the eight directions are used and the maximum radius value k along each direction is now not the same in all directions. This operator may be applied in all the four orientations in which it fits the picture element array, being rotated through 90° between applications, effectively increasing the field of view of the operator. The condition for detection of an object is that the brightness of the centre picture element must exceed by a threshold amount the average brightness of the picture elements along a direction for all of the directions used.

A reduction in size and complexity of the foregoing operators is possible by taking into account the alternating scanning motion of the pointer hereinafter described with reference to Figures 5 to 9 inclusive and as described in Patent Specification No copending Patent Application 47184/74. (Serial No. 1492179).

Provided that the vertical scans of the thermal detector remain for long enough on each horizontal bearing, the operator size can be reduced to about one half that of the operators described above. The processing of the lower half of the operator is performed during the up scan whereas the upper half of the operator is processed during the down scan. Referring to Figure 4, the i and j coordinates of the picture elements used in each scan are given according to Figure 2 (a). In order to further simplify the required electronics, a reduction in size from 5×5 to 3×3 is implemented. This new detector is described as follows with reference to Figure 2.

For each direction d:-

$$J_{1d} = p(0) - p(-1) \text{ i.e. 4 negative directions}$$

$$J_{2d} = p(0) - p(1) \text{ i.e. 4 positive directions}$$

For the Up scan, $R = 1$ if $J_{1d} \geqslant T$ for $d = 1$ and 2 and 3 and J_{14} or $J_{24} \geqslant T$

and $R = 0$ otherwise.

For the Down scan, $R = 1$ if $J_{2d} \geqslant T$ for $d = 1$ and 2 and 3 and J_{14} or $J_{24} \geqslant T$

and $R = 0$ otherwise.

In other words on any one scan the brightness of the centre picture element must exceed by a predetermined threshold the brightness of each of the three picture elements in retard of the centre picture element and also the brightness of at least one of the picture elements on either side of the centre picture element.

This object detection operator offers a great simplification over the preceding ones especially in the amount of storage (or delay); only one preceding value has to be accessed on only three columns, to give the three picture elements in retard, in contrast to four values on five columns in the preceding operators.

The detection of targets either hot or cold relative to the background can be achieved by computing the absolute values of the quantities J_d introduced in the definition of the operator. Circuits for implementing this operator are described later with reference to Figures 5, 6, 7, 8 and 9.

The critical threshold, i.e. the value for which the rate of false alarms is lower than a given value (10^{-3} for example) is on average, dependent on the standard deviation s of the signal in the whole scene. For the 5×5 corner detector in particular, it is possible to achieve a satisfactory rate of false alarms provided that the threshold is higher than an amount given by the expression $\alpha\ s^n$ with $\alpha \simeq 2 \pm 0.5$ levels of the digitised output of the thermal detectors and $n \simeq 0.5 \pm 0.1$.

The foregoing three embodiments of the invention can be summarised as follows.

The first one uses an input data the signal from seventeen cells contained in a square 5 × 5 and, for example, it may detect and locate in the scene the presence of small objects one to three cells wide, hotter than the background by, for example, 4.5 of the temperature window of the detector. It rejects any other thermal features such as lines, large objects or edges.

The second object detection operator recognises and locates the presence of small

features and also indicates corners of large objects.

Both operators can be implemented with the circuits described with reference to Figures 10, 11 and 12. They necessitate at least four stages of delay for each of five thermal detectors.

The third operator has been specifically designed to reduce the cost and size of the hardware realization. It requires only one stage of delay and a line of three photosensitive cells scanning transversely to the line of cells.

A slight modification of the operators (which can be achieved using a switch in the circuits) enables the recognition of cold as well as hot objects as compared to the local background.

A further embodiment of the invention will now be described in greater detail, by way of example, with reference to Figures 5 to 9 inclusive of the accompanying drawings in which:-

Figure 5 shows a schematic system block diagram of an equipment using the 3×2 operator described with reference to Figure 4.

Figure 6 shows a practical version of a channel amplifier.

Figure 7 shows a practical version of a sample-and hold circuit.

Figure 8 shows a practical version of a set of comparators and logic circuits implementing the 3×2 operator.

Figure 9 shows a practical version of a display drive circuit.

Referring to Figure 5, a scanning device 1 scans a real image of an external natural infra-red scene 2 vertically past a horizontal row 3 of seven infra-red detectors, a, b ......g. The scanning motion is oscillatory at 8 Hz, the up and down scans being of equal duration and of nearly constant speed. An apparatus for providing such a scanning motion is described in Patent Specification No. Copending Patent Application No. 47184/74. (Serial No. 14921/79).

Each of the detectors, a, b ......g has an amplifier 4, described below with reference to Figure 6. The output of each amplifier 4 is passed to direct, or "real-time" outputs a_1 b_1 ......g_1 respectively and to "sample-and-hold" (S/H) circuits 5 described below with reference to Figure 7. The outputs a_2, b_2 ......g_2 of the S/H circuits 5 provide the amplifier outputs delayed by a time corresponding to one picture element and hence provide the information for the lower row of elements of the operator of Figure 4.

Each of the five comparators 6, 7, 8, 9 and 10 implements one of the terms of the said operator. In detail, comparator 6 subtracts a_2 the voltage signal of delayed picture element *a* and a voltage corresponding to a threshold T from b_1, the real time voltage signal of picture element b. If the result is positive the output of a high gain amplifier in comparator 6 is a voltage of defined amplitude independent of the input voltages and represents a binary digit '1'. If the result is negative, the corresponding output is a near-zero voltage and represents a binary digit '0'. Thus, the quantity:-

$$b_1 - a_2 - T$$

is evaluated and converted to a binary decision. Likewise the quantities:-

$$b_1 - b_2 - T; \quad b_1 - c_2 - T; \quad b_1 - a_1 - T \quad \text{and} \quad b_1 - c_1 - T$$

are evaluated by comparators 7, 8, 9 and 10 respectively.

Logic elements 11 and 12 provided the 'AND' and 'OR' logic operations required by the operator logic described with reference to Figure 4. Thus a '1' output is only supplied along line 13 when the comparators 6, 7 and 8 all provide a '1' output and either comparator 9 or 10 provides a '1' output. These comparators and logic are described with reference to Figure 8.

A display drive circuit 14 converts the '1' output from the logic circuitry to a signal capable of driving a light emitting diode (L.E.D) at b′ at a fixed brightness.

Four other corresponding sets of five comparators and a display drive circuit apply the same operator logic to the amplifier output groups b_1 c_1 d_1 b_2 c_2 d_2; c_1 d_1 e_1 c_2 d_2 e_2; d_1 e_1 f_1 d_2 e_2 f_2 and e_1 f_1 g_1 e_2 f_2 g_2 to provide drives for the L.E.D.'s c′, d′, e′ and f′ respectively.

The five L.E.D. visual outputs are viewed by eye through a scanner 16 driven in synchronism 17 with scanner 1. In practice scanner 1 is a mirror and scanner 16 is a small portion of the same mirror. Visual persistance reconstructs a picture having picture elements in vertical scan lines in five possible positions. By optical means not shown, this picture is superposed on a visual version of the original scene 2.

A switch 18 is actuated by the scan drive circuit 17 to switch the output of the delay drive circuits 14 from one set of L.E.D.'s b′ to f′ inclusive to a second set of L.E.D.'s b″ to f″ inclusive at the end of each scan travel of the scanner 16. Thus the reconstituted picture is displayed by L.E.D.'s b′ to f′ on the UP scan and by L.E.D's b″ to f″ on the DOWN Scan. The two sets of L.E.D.'s are separated by a distance which compensates for delays in signal processing in the equipment. The UP and DOWN displayed pictures are thus shown in registration with one another.

Referring to Figure 6, a practical version of amplifier 4 of Figure 5 is shown. Commercially available integrated circuits C810/S1 and µA 776 are used to provide voltage gains of 300 and 6.8 respectively. A bandwidth of 1.5 Hz to 2 KHz is provided. The scan frequency of 8 Hz and the vertical picture definition combine to give 3500 picture elements per second i.e. a line pair frequency of 1750 Hz. The upper limit of bandwidth, 2 KHz, gives good pulse visibility. The overall gain of the thermal detector and amplifier and the high-frequency cut-off of all seven channels are matched to within ± 2%. The photoconductive thermal detector element is connected between the terminals ^{a}in and ^{a}comm.

Referring to Figure 7, a practical version of a 'sample-and-hold' circuit shown at 5 in Figure 5 is shown. The input on terminal 20 is supplied by the output of the amplifier shown in Figure 6. A switched gain control 21 passes the detector signal direct to output 22 for direct display use if required. Switch 21 also feeds a buffer amplifier 23 through an A.C. coupling R1 and C1 which limits the low frequency response to 7 Hz. The matching of the 7 channels in this respect is important because a direct level comparison is later made between adjacent channels. The "black level" which enables this comparison to be made is the average signal level seen by each channel in the period determined by this coupling time constant. Due to the vertical scanning and the small horizontal subtense of the detector array, it can reasonably be assumed that all the elements of the array "see' the same mean temperature. Vertical subtense seen by each element is 20 times the angular width of the row 3 of infra-red detectors.

The output of the D.C. buffer amplifier is available in real time, 24, and is also sampled by a 'sample + hold' using a gated transconductance amplifier 25 RCA type CA 3080 A. The sampling rate is 3.5 KHz, which is equal to the picture-element scan rate, sample pulses being applied at terminal 26 to 'enable' amplifier 25. When 'enabled', amplifier 25 charges capacitor C2 up to a voltage determined by the input 28. C2 is a low dielectric storage mica capacitor to avoid the signal due to the previous picture element having any effect on the present sample. The 'held' output is available on terminal 27 as signal a_2, for example. In the following description, a suffix '1' to a channel letter indicates a real time signal and a suffix '2' to a channel letter indicates the stored signal of the previous picture element.

Referring to Figure 8 a practical version of the comparators 6, 7, 8, 9 and 10 and the logic elements 11 and 12 shown in Figure 5 is shown. Ten comparators, 30 to 39 inclusive are shown. The five even numbered comparators 30 to 38 implement the five decision terms of an operator detecting 'hot' targets against a cold background and the five odd numbered comparators 31 to 39 implement the same operator logic for 'cold' targets against a warm background. Comparator 30, for example, implements $b_1 - a_2 - T$, one of the five terms of the operator. Each comparator consists of a gated transconductance amplifier RCA type CA 3060 having two balanced voltage input terminals 40 and 41 and a single current output terminal 42. When working into a high load resistance 43, R35, the voltage gain of the amplifier is sufficiently high that signals applied to the input which are materially more than the noise level on such signals are able to drive the amplifier output to saturation giving a '1' output or to turn it off completely giving a '0' output. Input b_1 is applied through a 10K resistor to the positive input terminal 40 and a 470K resistor connected to a bias voltage source 44. Input a_2 is applied through a 10K resistor to the negative input terminal 41 and a 470K resistor connected to the threshold voltage source T. Thus the sum of a_2 and T is subtracted from b_1 at the input terminals of amplifier 30. Similarly the other four amplifiers 32, 34, 36 and 38 evaluate the other four terms of the 'hot' operator. Amplifier 31 functions identically to amplifier 30 except that a_2 goes to the positive input and b_1 goes to the negative input, thus implementing the corresponding term of the 'cold' operator. Output 46 is only a '1' when b_1 is less than a_2 by the threshold T.

Each comparator amplifier has an enabling input: 47 for amplifier 30 and 48 for amplifier 31. An appropriate D.C. signal on 47 'enables' amplifier 30, so that the latter is able to respond to its input signals. If not so enabled, the output 42 remains at '0' regardless of input. The enabling inputs of the five 'hot' target comparators are connected together to a common input t+ and similarly for the 'cold' comparators to input t−. Thus with appropriate D.C. signals on t− and t+ either one or both or neither of the 'hot' and 'cold' operators can be brought into operation.

The 'hot' and 'cold' operator outputs are combined and the subsequent logic performed

by the CMOS logic circuits 49, 50, 51, 52 and 53. Circuits 49, 50 and 51 each combine 'hot' and 'cold' term outputs. For example, a '1' on either or both of outputs 42 and 46 produces a '0' on the output of circuit 49. Circuit 52 combines four inputs with the same non-exclusive inverting 'OR' logic. Circuit 53 only produces a '1' output on terminal 54 if all four inputs are '0', thus implementing the combining 'AND' logic of the operator. There are four other complete sets of ten comparators giving five processed outputs. These are needed to simultaneously process the five groups of three adjacent detector channels per group that can be obtained from the seven original channels. The threshold T may be adjustable and may be set manually by the operator or set automatically at a level giving a low false alarm rate. This may be obtained when a threshold level four times the average variation of the signal level is used.

Referring to Figure 9 a practical display drive circuit as shown at 14 in Figure 5 is shown. A feature of this circuit is that a D-type flip-flop 60, Commercial type MC14013, is used to store the operator logic output for the duration of a picture element. The operator logic output will change between '0' and '1', in general, during a picture element as the 'real time' signal varies. To provide an acceptable display, the logic output 61 is sampled by a clock pulse 62 and stored in the D-type flip-flop 60. Output 63 remains constant at '0' or '1' for the duration of one picture element. The following logic in Figure 9 allows an alternative input to be displayed corresponding to a normal grey-scale thermal picture either alone or in combination with the operator processed picture. Suitable amplifiers and phase inverters follow to provide an output suitable for driving the light emitting diode.

The embodiment described above takes advantage of the equal speed up and down scans to break the operator into the two smaller 3×2 operators. A single sample-and-hold circuit is required per channel. Provision is made for detecting hot or cold targets against contrasting backgrounds.

Another advantage of the scanning method is that it allows the detector bandwidth to be minimised for optimum signal-to-noise ratio and also a constant-frequency clock to be used for the operator. The performance of the equipment does not depend on where the target appears within the vertical field-of-view. Also the time delay between scanning across a target and display the presence of the target is constant (about 1 picture-element period). This time delay can then be compensated for by a mechanical shift of the L.E.D.'s (light emitting diodes) or by using two line arrays of L.E.D.'s separated by 2 picture elements as shown in Figure 5.

A second embodiment of the invention will now be described, by way of example, with reference to Figures 10 to 12 inclusive of the accompanying drawings in which:-

Figure 10 shows a set of seven analogue to digital converters.

Figure 11 shows a matrix store, and

Figure 12 shows vector combining logic for one channel.

The processor of the second embodiment implements the 5×5 corner-detecting and 5×5 point-detecting operators, including the asymmetric operator described herein. Digital techniques are used, and serial arithmetic has been chosen as giving the simplest approach. Referring to Figure 10 an analogue-to-digital converter (ADC) is used. For each detector channel a shift register 70 counts clock pulses until the ram of the ADC exceeds the input signal level, determined by a comparator (CA 3060). At the end of the picture-element period the seven bit word (+1 spare zero) representing the sampled signal level is transferred to the first stage of a 64 bit shift register 80 of Figure 11.

The ADC samples the input signal level every ½ picture element period.

Referring to Figure 11, the matrix store 80 (64-bit shift registers) contains in digital form the signal level at every ½ picture-element period, but the information is available at only 16-bit intervals, i.e. every other word.

However only each alternate word is required by the arithmetic unit (NOT SHOWN) to implement the operator. The operator is however "calculated" every ½ picture-element period (i.e. at 4 × the system bandwidth) to ensure that point targets are not missed by sampling "in phase" with the target signal.

Referring to Figure 12, the 5 × 5 operators require the calculation of 8 vectors or operator terms. The result of each calculation, as a binary decision, is shown as inputs b_0, b_2; b_0, d_2; etc to gate L9. Vectorcombining logic L9 or L10 then determines whether the signs of the 8 vectors constitutes either a point or a corner respectively. The arithmetic unit can be switched so as to detect either hot targets or cold targets. The equipment may combine this unit with the analogue display.

Much common circuitry is used for corner detector and point detector arithmetic units-only different vector combining logic being used. For example, all the decision inputs b_o, b_2, etc feed both L9 and L10. The detectors are interlaced to give answers at twice the sampling frequency. Portions of the circuitry may be multiplexed for further economy.

The following sets of values and components are given by way of illustration for each of the Figures 6 to 12 inclusive.

Figure 6

A1	C810/S1
A2	μA776
V1	+5 volts
V2	−5 volts
C3	1 uF
C4	120pF
R2	100K
R3	680K
R4	650K
R5	47K
R6	47K
R7	10K
R8	560K

Figure 7

Amplifier	23	μA776
Amplifier	25	CA 3080A
	V3	+5 volts
	V4	−5 volts
	C5	1 μF
	C6	120pf
	C7	0.1 μF
	C8	0.1 μF
	C9	68 μF
	R9	6K8
	R10	2K7
	R11	1K
	R12	47K
	R13	100 K
	R14	100 K
	R15	100 K
	R16	10 K
	R17	560 K
	R18	2K2
	R19	10M
	R20	2K2
	R21	220Ω
	R22	2K7
	R23	2K7
	Z1	E295ZZ/01
	Z2	E295ZZ/01
	T1	BCY71A
	T2	BFR29
	T3	BC109

Figure 8

Amplifier	36	⅓ CA 3060 AD
Amplifier	30	⅓ CA 3060 AD
Logic Circuit	52	½ MC 14002
Logic Circuit	49	¼ MC 14001
Logic Circuit	50	¼ MC 14001
Logic Circuit	51	¼ MC 14001
Logic Circuit	53	¼ MC 14002
	R24	10K
	R25	470K
	R26	10K
	R27	470K
	R28	100K
	R29	10M
	R30	10K
	R31	470K
	R32	10K
	R33	470K
	R34	100K
	R35	10M
	R36	100Ω
	R37	10K
	R38	10K
	C10	0.1 uF
	C11	0.1 uF
	C12	0.1 uF

Figure 9

	A3	MC14010
Logic circuits	64, 65, 66	¾ MC14011
Logic circuit	60	½ MC 14013
Logic circuit	67	¼ FJH 291
	D1	BAV 10
	T4	BCY 71
	V5	+5 volts
	V6	+4 volts
	R39	2K2
	R40	10K
	R41	100 %

Figure 10

A4	uA 776
A5	uA 776
A6	CA 3060
A7	CA 3060
L1	MC 14013
L2	MC 14013
L3	MC 14021
L4	MC 14021

Figure 11

L5	MC 14006
L6	MC 14006
L7	MC 14517
L8	MC 14517

Figure 12

L9	MC 14501
L10	MC 14002
L11	MC 14011
L12	MC 14011
L13	MC 14011

WHAT WE CLAIM IS:-

1. Picture processing apparatus for application to a picture comprising a regular two-dimensional array of picture elements each of which is the centre picture element of a plurality of radiating straight lines of contiguous picture elements aligned in radial directions and in which each picture element has a brightness value, said apparatus comprising means for determining the average brightness of one or more picture elements in such a radial direction, said average being taken over a number of picture elements small compared to the number of picture elements in the maximum dimension of the picture and excluding the said centre picture element, and means for providing an output signal when the said average brightness differs from the said centre picture element brightness by at least a predetermined threshold amount of the same sign on at least half of the said radial directions.

2. Apparatus as claimed in Claim 1 wherein said regular two-dimensional array comprises regular spaced rows and regular spaced transverse columns of picture elements and wherein the outermost picture element used for determining said average brightness in each radial direction is contained within and is at the boundary of a rectangular array of picture elements having its sides parallel to said rows and columns respectively.

3. Apparatus as claimed in Claim 2 wherein said rectangular array is a square having a side of five picture elements.

4. Apparatus as claimed in Claim 3 wherein the said centre picture element is at the centre of the square of picture elements.

5. Apparatus as claimed in Claim 4 wherein the output signal is obtained only when said average brightness differs from the said centre picture element brightness by at least a predetermined threshold amount of the same sign on all of the said radial directions.

6. Apparatus as claimed in Claim 4 wherein the output signal is obtained when said average brightness differs from the said centre picture element brightness by at least a predetermined threshold amount of the same sign on at least one radial direction of each of all four pairs of diametrically opposed radial directions.

7. Apparatus as claimed in Claim 3 wherein said centre picture element is adjacent, along either a row or a column, to the centre of the square of picture elements.

8. Apparatus as claimed in Claim 2 wherein said rectangular array is a square having a side of three picture elements, said centre picture element is at the centre of the square of picture elements, and said average brightness is that of one picture element adjacent to said centre picture element.

9. Apparatus as claimed in Claim 8 wherein said output signal is obtained only when said average brightness differs from the said centre picture element brightness by at least a predetermined threshold amount of the same sign on at least four contiguous radial directions.

10. Apparatus as claimed in any preceding claim comprising means for scanning the picture with a line array of radiation sensitive cells in a direction transverse to the said line of cells and means for sampling and storing the output of said cells at regular intervals so as to provide the brightness values of said regular two-dimensional array of picture elements.

11. Apparatus substantially as described with reference to Figures 1 to 4 inclusive of the accompanying drawings.

12. Apparatus substantially as described with reference to Figures 4 to 9 inclusive of the accompanying drawings.

13. Apparatus substantially described with reference to Figures 10, 11 and 12 of the accompanying drawings.

B.T. STEVENS,
Chartered Patent Agents,
Mullard House,
Torrington Place,
London. WC1E 7HD.
Agent for the Applicants.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1981.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1605009 COMPLETE SPECIFICATION
10 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 1

20-	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
21-	5	5	5	5	5	5	5	6	5	6	6	6	6	6	6	6	6
22-	5	5	5	5	5	5	5	5	5	5	6	5	5	6	6	6	6
23-	5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6
24-	5	5	5	6	6	6	6	7	6	7	7	7	7	7	7	7	8
25-	5	6	6	6	6	6	7	8	8	8	9	8	8	9	9	10	10
26-	5	6	6	6	6	7	10	13	13	13	14	14	12	12	13	15	14
27-	6	5	6	6	9	13	18	23	21	17	16	15	14	15	16	17	22
28-	5	5	5	7	13	19	22	31	31	24	18	17	15	16	17	21	31
29-	5	5	5	6	11	17	19	26	31	31	22	19	16	16	17	20	26
30-	5	5	5	7	9	13	16	18	23	25	21	17	15	14	14	15	17
31-	6	5	7	10	10	12	13	13	14	13	12	11	11	11	11	11	11
32-	5	5	8	12	14	13	13	14	16	15	12	10	10	10	11	12	13
33-	5	5	8	16	21	21	22	27	29	25	18	15	15	16	19	22	23
34-	5	5	6	7	8	10	10	11	11	12	12	14	16	17	17	18	19
35-	6	6	7	7	7	7	8	7	7	8	9	12	13	12	12	13	14
36-	6	6	6	7	6	7	7	7	7	7	8	9	9	9	9	10	11
37-	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
38-	6	6	7	6	7	7	7	7	7	7	7	7	7	7	7	6	7
39-	6	6	6	6	7	7	7	7	7	6	6	6	6	6	7	7	7
40-	7	7	7	7	7	7	8	7	7	7	7	7	7	7	7	7	7

Fig.1

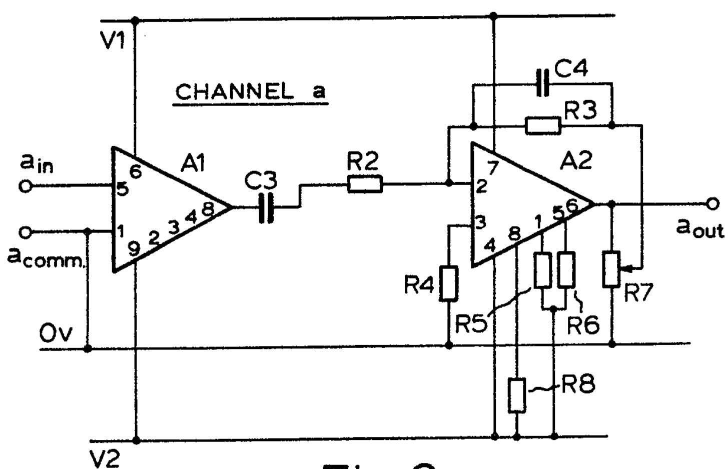


Fig.6

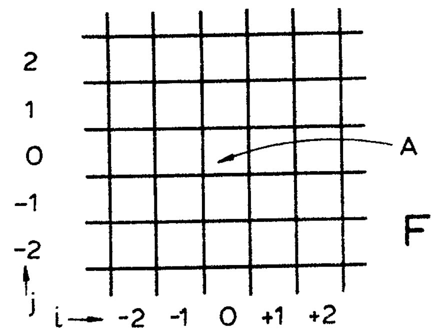


Fig.2a

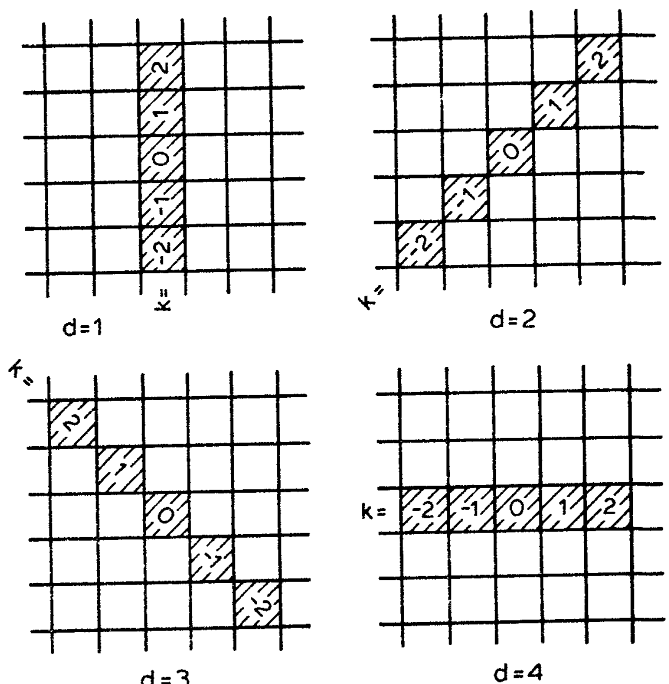


Fig. 2b

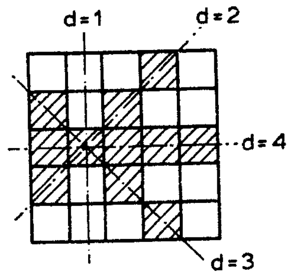


Fig.3

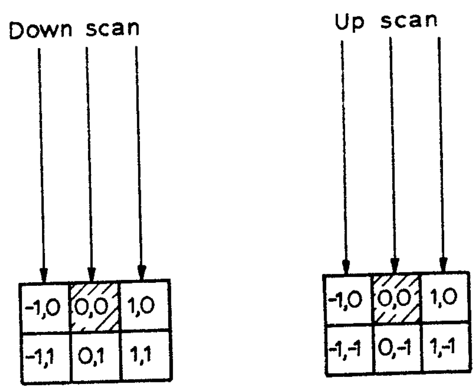


Fig.4

1605009 COMPLETE SPECIFICATION
10 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 4

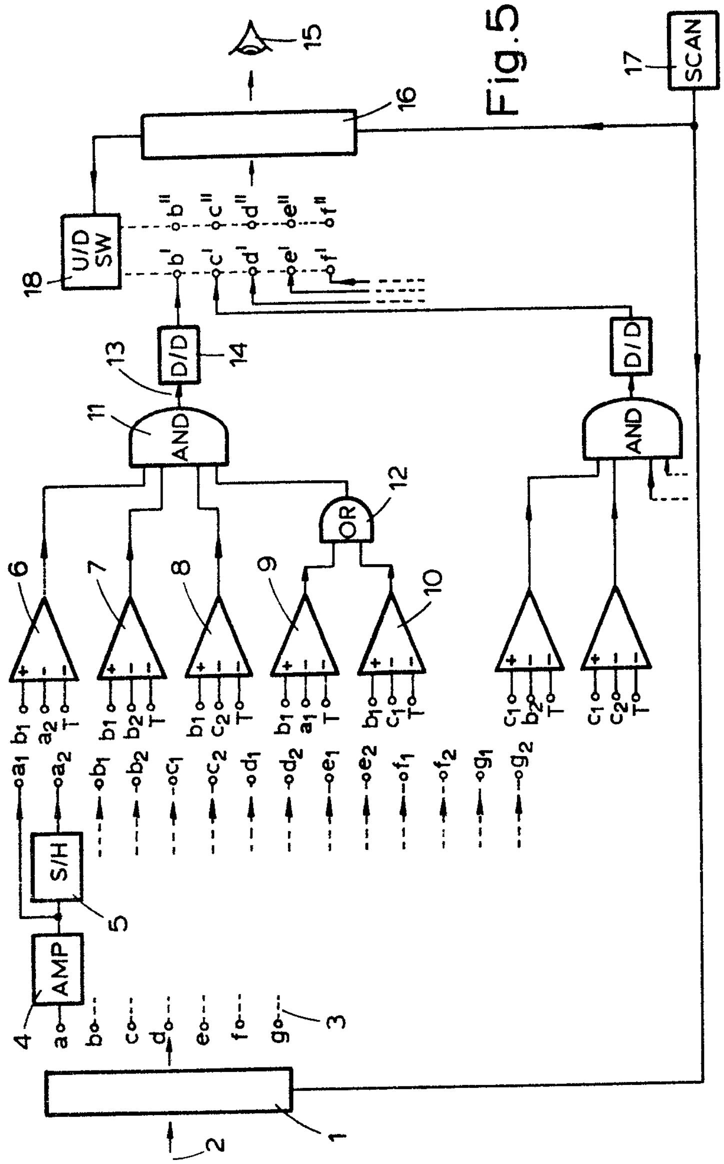


Fig.5

1605009 COMPLETE SPECIFICATION

10 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 5

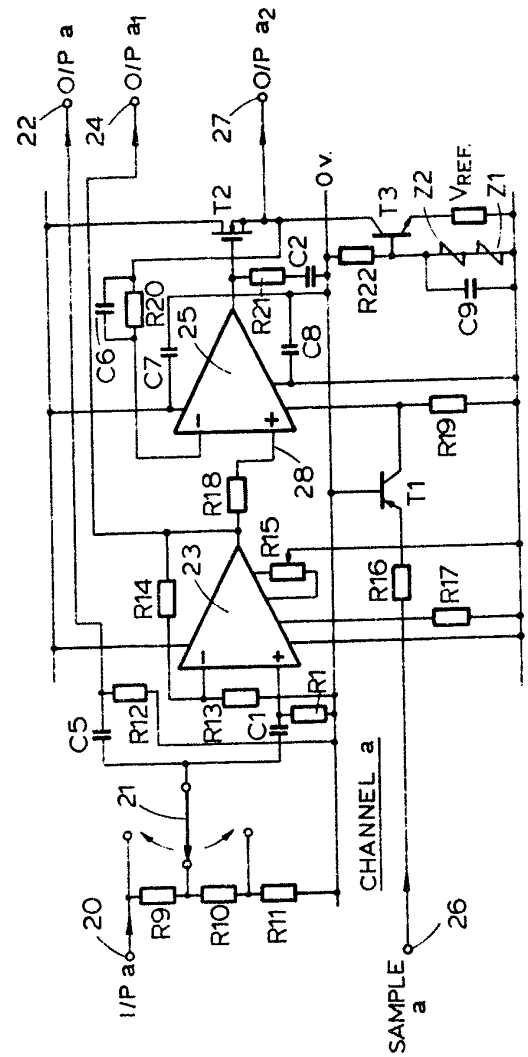


Fig. 7

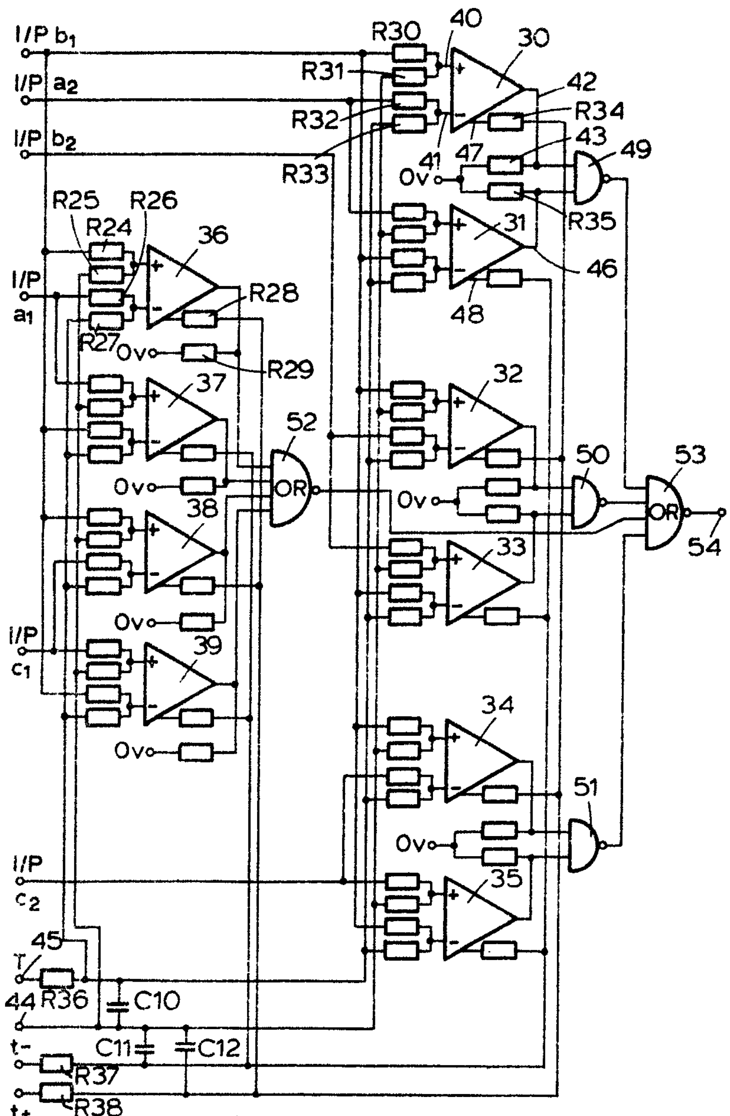

I/P b1
I/P a2
I/P b2
I/P a1
I/P c1
I/P c2
R24
R25
R26
R27
R28
R29
R30
R31
R32
R33
R34
R35
R36
R37
R38
C10
C11
C12
T
t-
t+
0v
OR
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54

Fig.8

1605009 COMPLETE SPECIFICATION

10 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 7

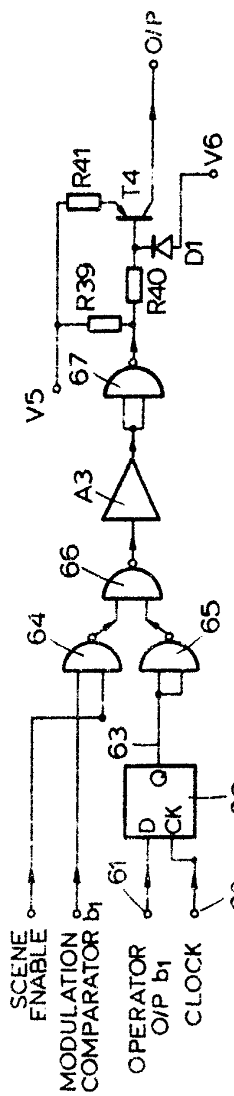


Fig. 9

1605009 COMPLETE SPECIFICATION

10 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 8

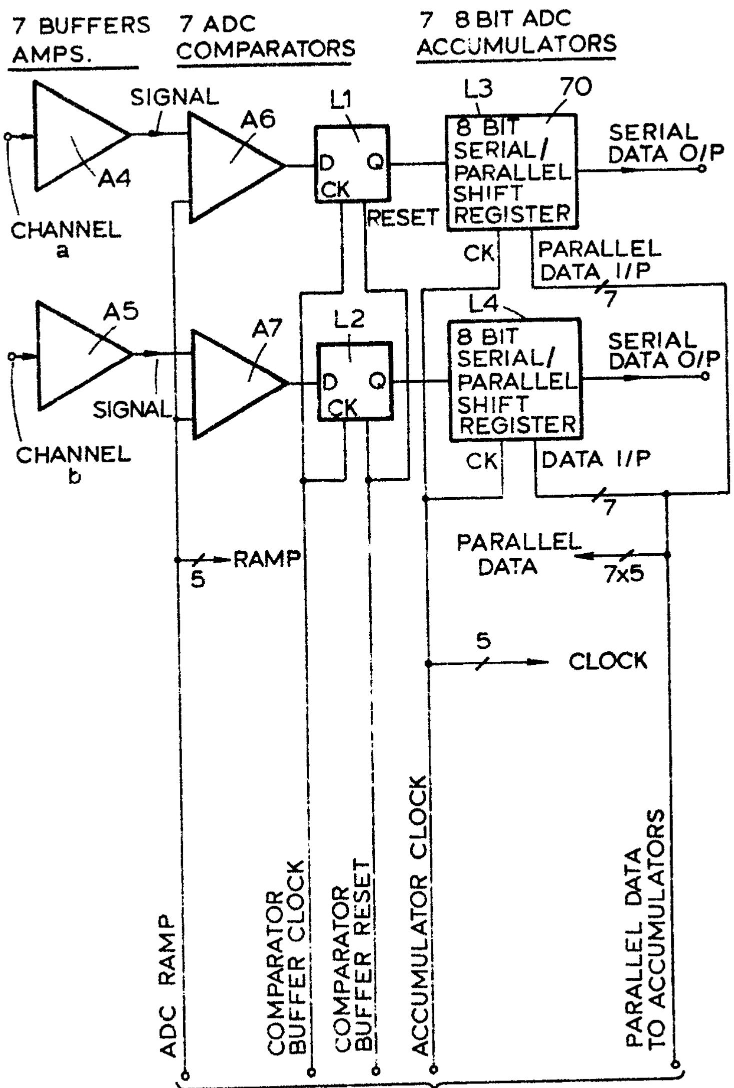


Fig.10

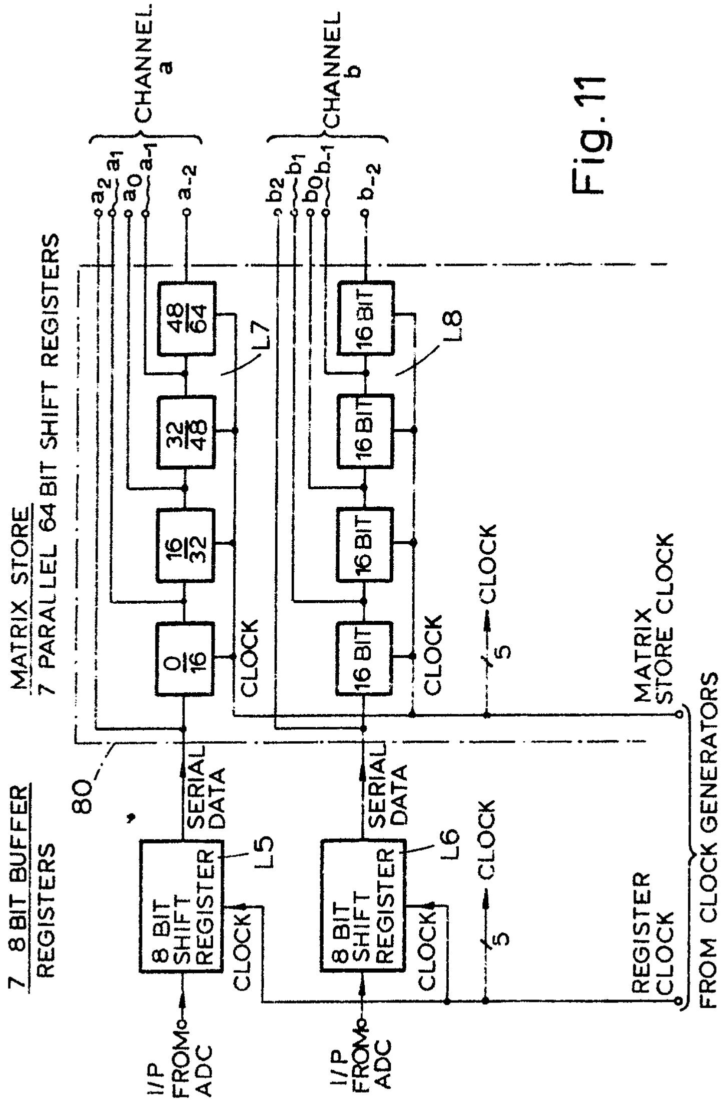

7 8 BIT BUFFER REGISTERS
MATRIX STORE
7 PARALLEL 64 BIT SHIFT REGISTERS
CHANNEL a
CHANNEL b
8 BIT SHIFT REGISTER
SERIAL DATA
I/P FROM ADC
CLOCK
16 BIT
REGISTER CLOCK
MATRIX STORE CLOCK
FROM CLOCK GENERATORS
L5
L6
L7
L8
80

Fig. 11

1605009 COMPLETE SPECIFICATION
10 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 10

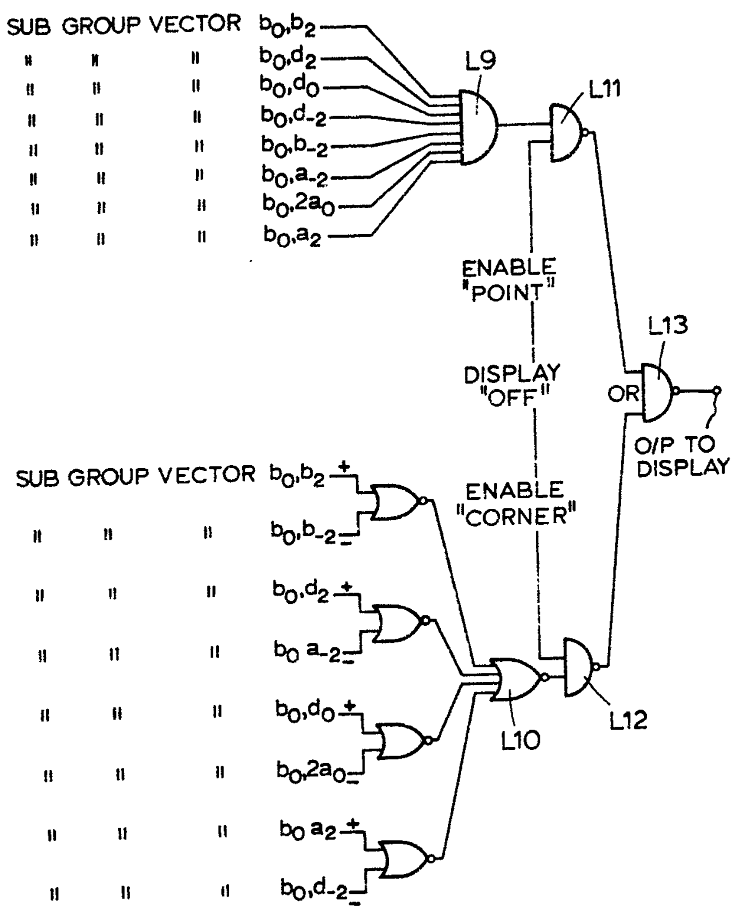


Fig. 12